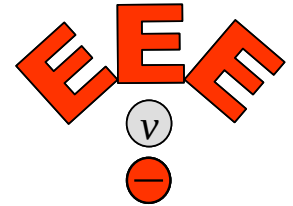




UCC

Coláiste na hOllscoile Corcaigh, Éire
University College Cork, Ireland



Photonic Signal Processing For Antenna and Radar Controls

By
Nabeel A. Riza

School of Engineering
University College Cork (UCC), Ireland
Email: n.riza@ucc.ie <http://soe.ucc.ie>

The Research Area is also called :

- **RF Photonics**
- **Microwave Photonics**

Phased Array Antenna Applications

- Military Radars
- Wireless Communications
- Radio-Astronomy
- Air Traffic Control Radars
- Mobile Platform Antenna Systems



Scientific American, 1998

ADVANCED PHASED ARRAY RADAR



US Air Force 27 m Diameter PAVE PAWS Radar (Alaska) for Missile Defense

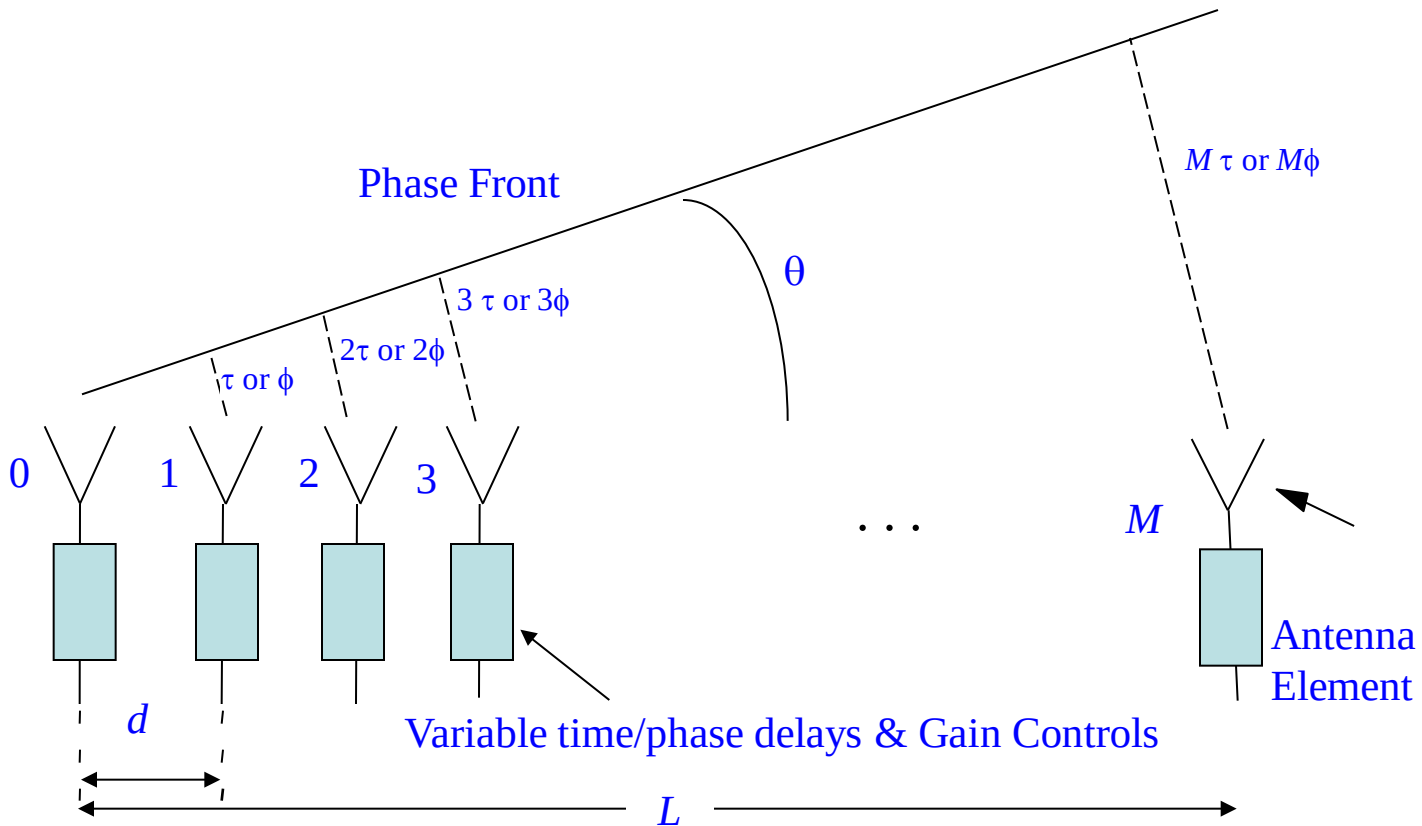
- Limited Bandwidth
- Massive Control Electronics

ULTIMATE GOAL:

SEE BETTER in 3-D
Range+Image

- Increase Inst. Bandwidth
- Use Time Delay Processing

Phased Array Antenna Beam Steering



Time Delays

$$\tau = \frac{d}{c} \sin \theta$$

Phase Delays

$$\phi = \frac{2\pi}{\lambda_{\text{rf}}} d \cdot \sin \theta$$

THE ULTIMATE CHALLENGE IN RF RADAR SYSTEMS

Achieve The Following Basic System Attributes:

- High Resolution 3-D Imaging at Long Range
using Efficient Compact Controls**

(See Small Targets at Far Away Distances)



A Solution



**Use Very Large Instantaneous Bandwidth
Large Aperture Microwave Radar Designs
Using Hybrid Optical & Electronic Controls**

THE IDEAL RF DELAY LINE FOR WIDEBAND RADAR CONTROLS

- DC to 18 GHz Tunable Bandwidth
- > 1 GHz Instantaneous Bandwidth
- > 16 bits of Time Delay Controls (> 65,536 settings)
- > 25 ns Time Delay Range
- < 0.35 ps Time Delay Resolution
- 1 microsec Reset times typical but as fast as 1 nsec

Today, to the Best of Our Knowledge, No Such Delay Line Exists.

APPROACH TO REALIZE THE IDEAL RF DELAY LINE

“Hybrid Optical Signal Processing” OR HOSP TECHNOLOGY

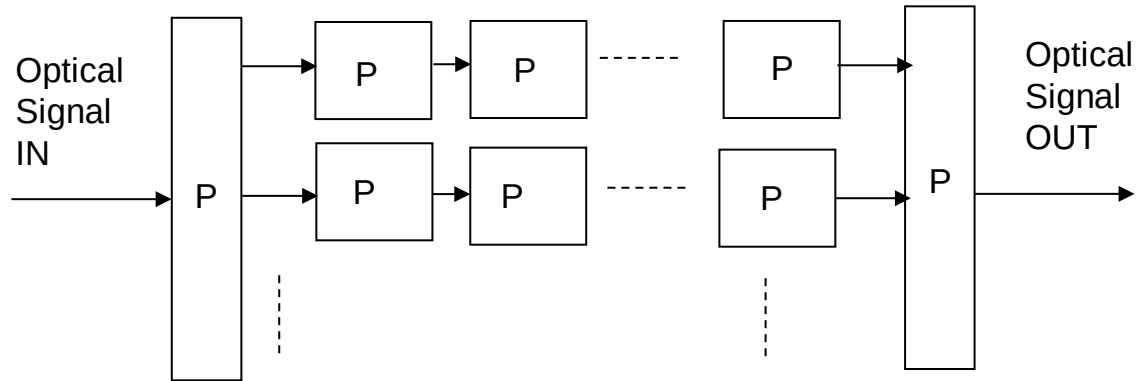


KEY IDEA* :

COMBINE **ANALOG** AND **DIGITAL**
OPTICAL PROCESSING

*** N. A. Riza, M. A. Arain, and S. A. Khan, "Analog-Digital Variable Fiber-Optic Delay Line," IEEE/OSA Journal of Lightwave Technology, vol.22, No.2, pp.619-624, Feb. 2004.**

PROPOSED HYBRID PHOTONIC SIGNAL PROCESSOR



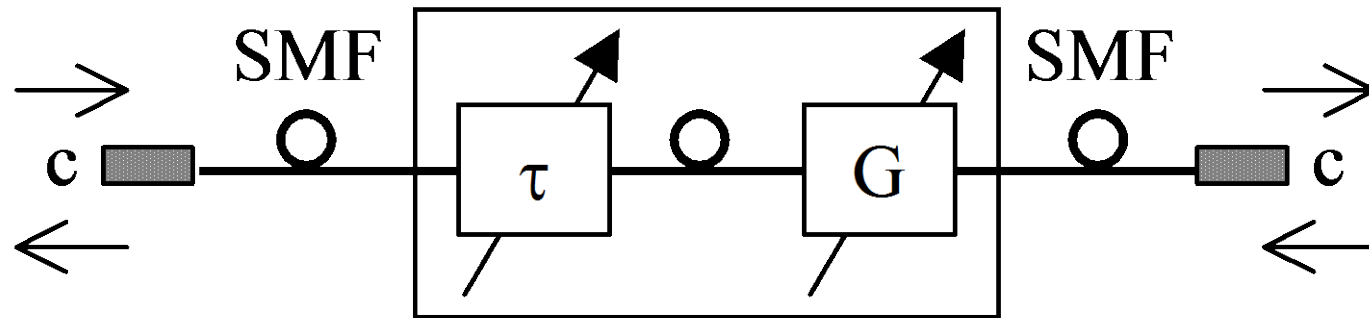
P: Analog or Digital Optical Processing Device or Module

Approach:

- 1: Parallel and Serial Processor **Optical Interconnections** &
- 2: Analog and Digital Independent Processing/**Controls**

Note: Optical signal in can have RF modulation of analog, digital, or hybrid type.

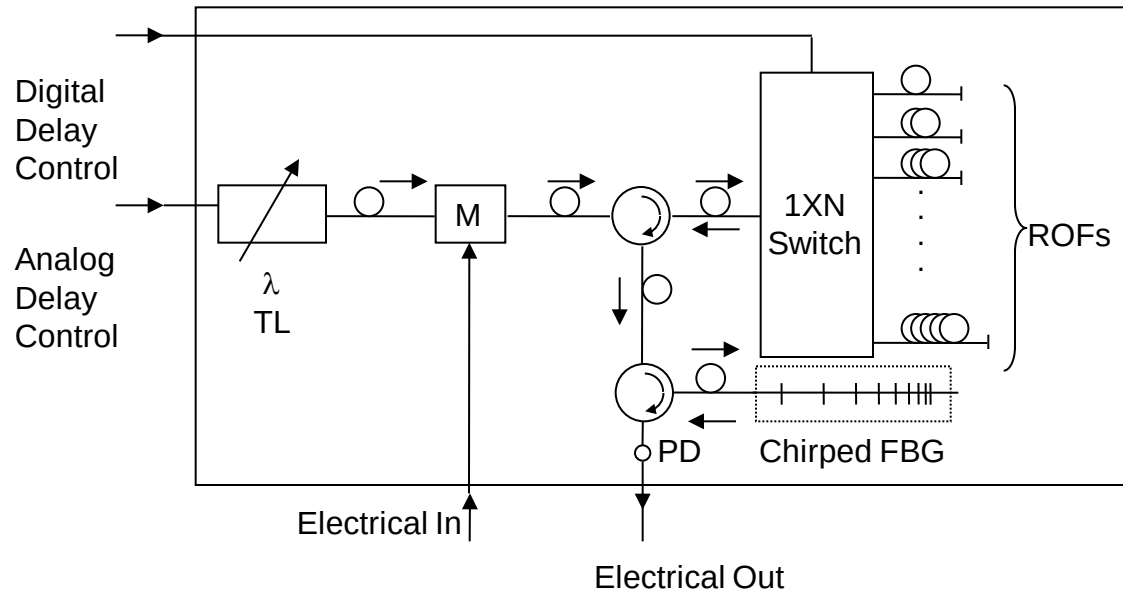
EXAMPLE UNIVERSAL PROCESSOR MODULE
KEY TO MANY SIGNAL PROCESSING OPERATIONS



Universal Processor Module

Need: Optical Time Delay PLUS Optical Gain/Attenuation Controls

THE PROPOSED SOLUTION: HOSP-BASED RF DELAY LINE



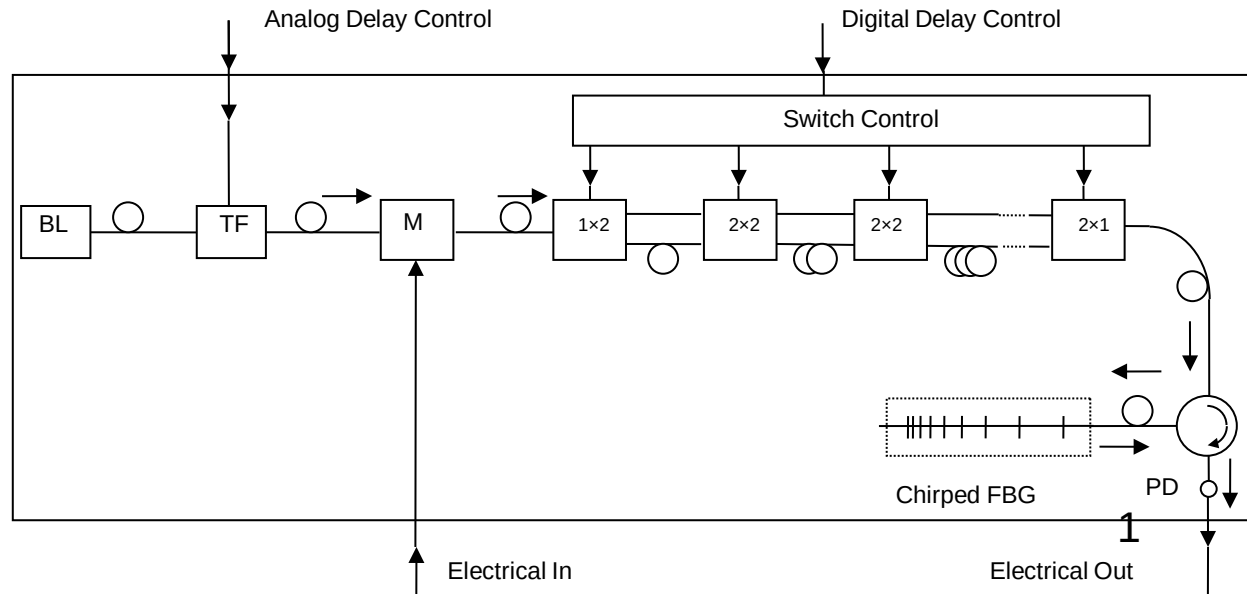
Analog Optics:

- Laser Wavelength Tuning
- Chirped Fiber Bragg Grating

Digital Optics:

- Digital Optical Switch
- Pre-cut Optical Fibers

AN ALTERNATE DESIGN OF THE PROPOSED DELAY LINE (Via Serial Processing)



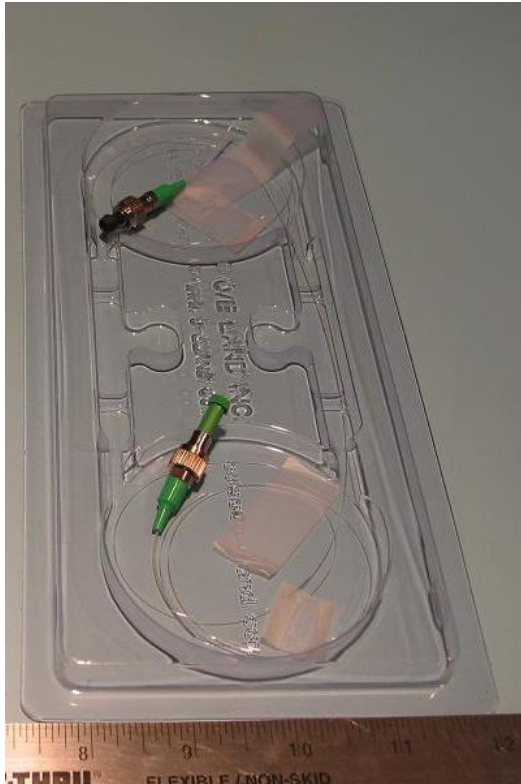
Analog Optics:

- Laser Wavelength Tuning
- Chirped Fiber Bragg Grating

Digital Optics:

- Digital Optical Switch
- Pre-cut Optical Fibers

HARDWARE FOR PROOF-OF-CONCEPT EXPERIMENTAL DEMONSTRATION



1550 nm band fiber-optic fiber with Chirp Fiber Bragg Grating (CFBG) and two fiber connectors.

CFBG Optical Loss= 0.36 dB

CFB Optical Bandwidth= 22.88 nm

CFBG Dispersion = 35.2 ps/nm

Laser Tuning = 1536 nm – 1560 nm =24 nm

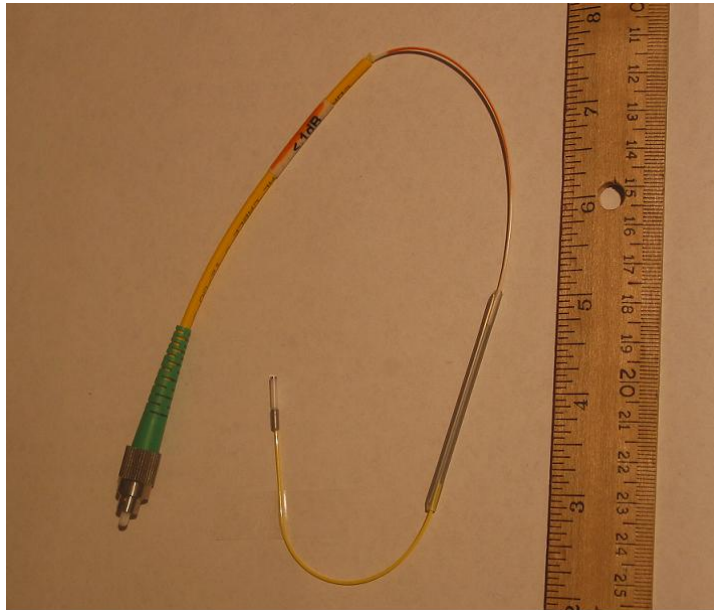
Present Laser Tuning Speed = 1 ms

Tuning Resolution = 0.01 nm

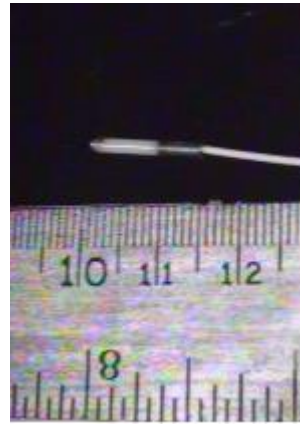
Max Analog Delay = 805.4 ps

Tuning Delay Resolution= 0.35 ps

HARDWARE FOR PROOF-OF-CONCEPT EXPERIMENTAL DEMONSTRATION



1550 nm band 40 cm fiber with reflective fiber tip and one fiber connector.



Tip Loss
0.7 dB

Time Delay Range	Control Mechanism	Active Switch Port	Fiber Length at switch port
0-800psec (0 to T)	Analog (1536-1560nm)	1	40cm
800-1600 psec T to 2T	Analog+Digital	2	48cm
1.6-2.4nsec 2T to 3T	Analog+Digital	3	56cm
23.2 – 24.0 nsec 29T – 30T	Analog+Digital	30	272cm
24.0 – 24.8 nsec 30T – 31T	Analog+Digital	31	280cm
24.8 – 25.6 nsec 31T – 32T	Analog+Digital	32	288cm

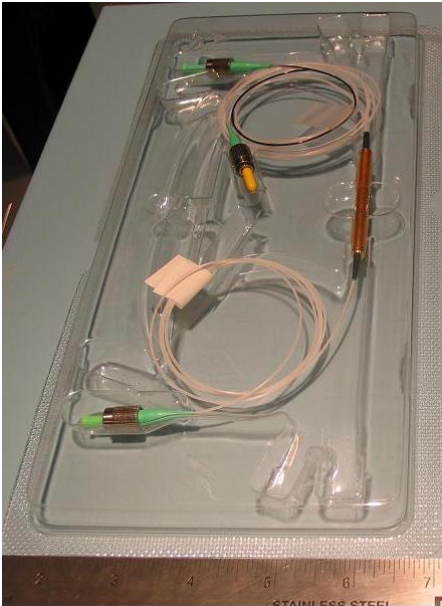
Fiber lengths:

8 cm Two-pass Fiber = 800 ps →

40 cm, 48 cm, 56 cm, 272 cm, 280 cm, 288 cm

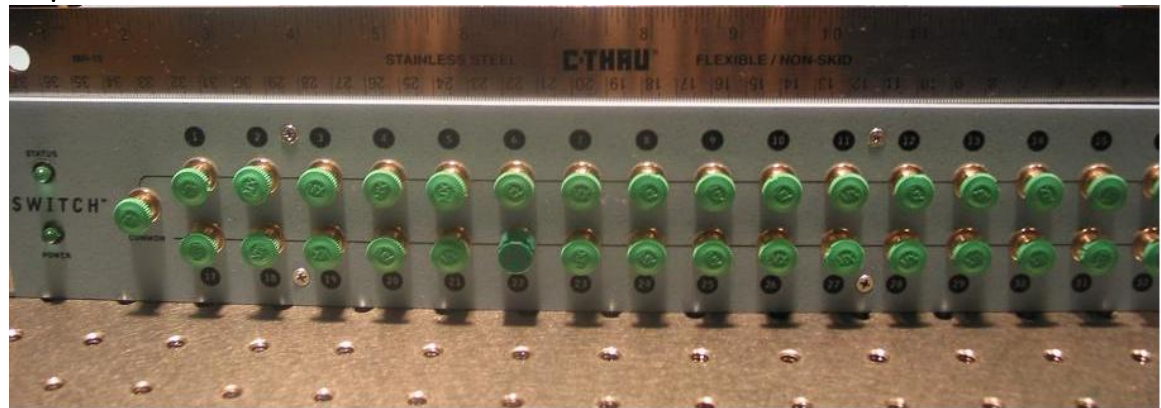
8 cm fiber Increase gives 800 ps delay (=Analog Delay)

HARDWARE FOR PROOF-OF-CONCEPT EXPERIMENTAL DEMONSTRATION



1550nm band fiber-optic
Circulator with three fiber
Connectors

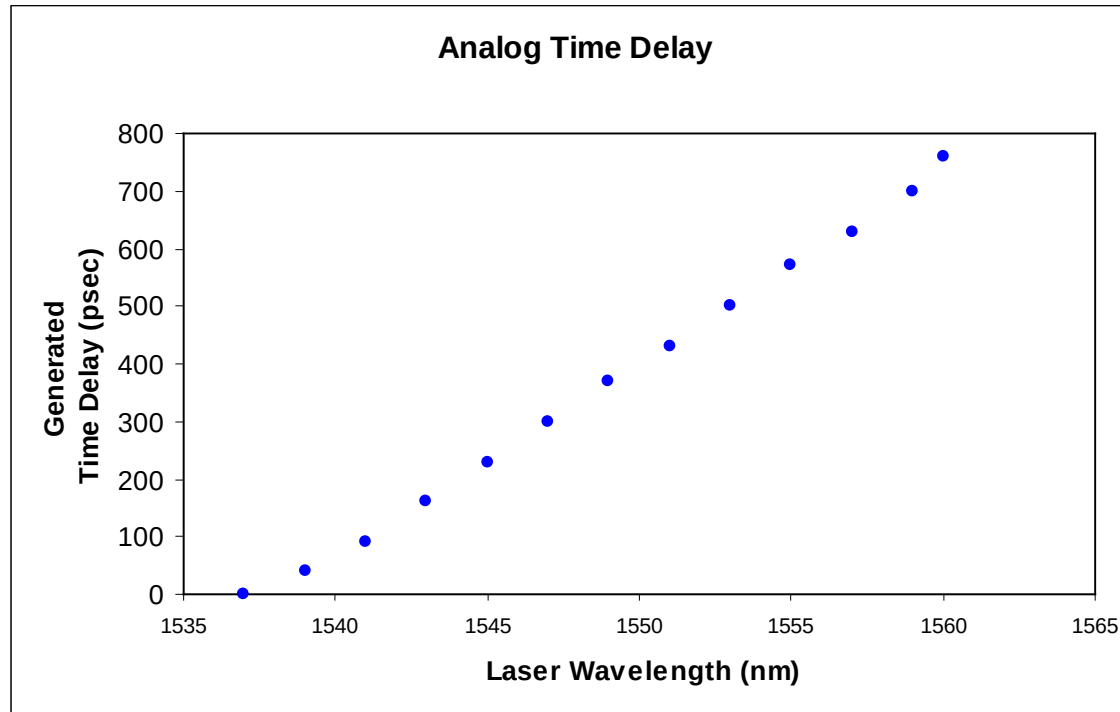
3 port Fiber-Fiber
Optical Loss= 1.29 dB



1550nm band fiber-optic 1x32 switch
with 33 fiber connectors
(Opto-mechanical Switch)

Fiber-Fiber Optical Loss = 0.47 dB

PROOF-OF-CONCEPT EXPERIMENTAL DEMONSTRATION



**Tuning Resolution:
0.01 nm**

↓
0.35 ps

Analog Time Delay Operation

22.5 nm (1537.5 nm to 1560 nm) Laser Tuning Gives 800 ps band

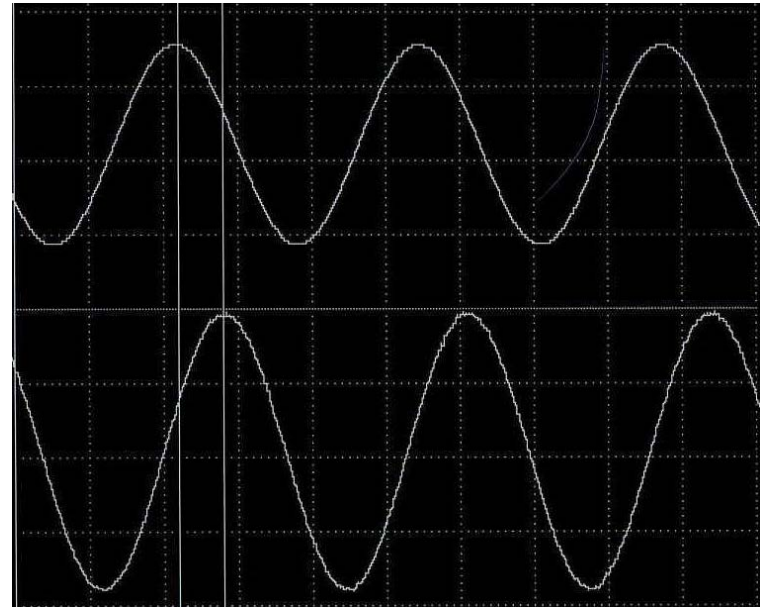
Used RF-Optical Modulator Bandwidth: 125 MHz (Capability: 10 GHz)

Used Optical-RF Detector Bandwidth: 125 MHz

PROOF-OF-CONCEPT EXPERIMENTAL DEMONSTRATION

Top Trace: Reference RF

Bottom Trace:
RF from Photodetector in module.



RF: 125 MHz

Laser at 1547 nm and Port 2 selection = 1200 ps delay

800 ps = Port 1 + Port 2 Differential 8 cm ROF
and 400 ps is from the Chirp FBG delay at 1547 nm Reflection.

PROOF-OF-CONCEPT EXPERIMENTAL DEMONSTRATION

Top Trace: Reference RF

Bottom Trace:
RF from Photodetector in module.

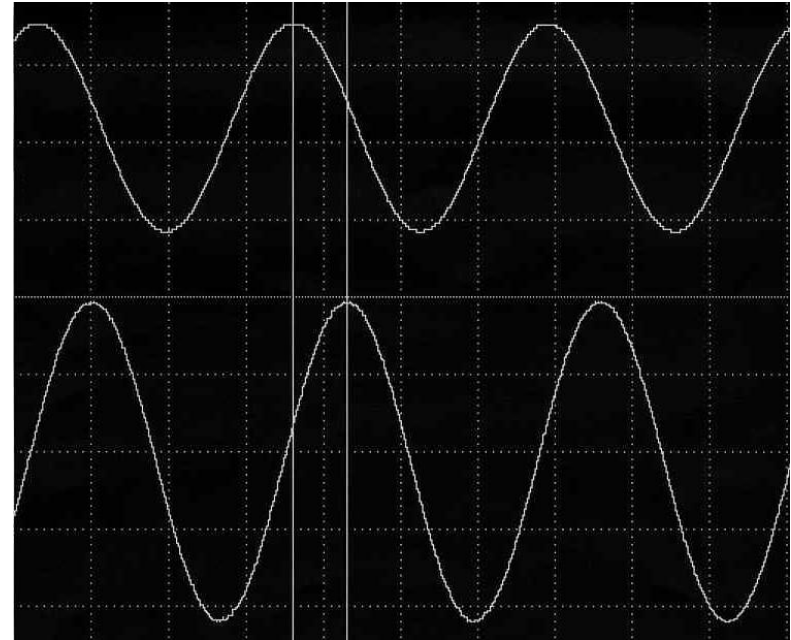


Figure Shows the 1553 nm and port 2 selections giving the desired 1400 ps delay where 800 ps is from the additional 8 cm ROF and 600 ps is from the Chirp FBG delay.

PROOF-OF-CONCEPT EXPERIMENTAL DEMONSTRATION

Top Trace: Reference RF

Bottom Trace:
RF from Photodetector in module.

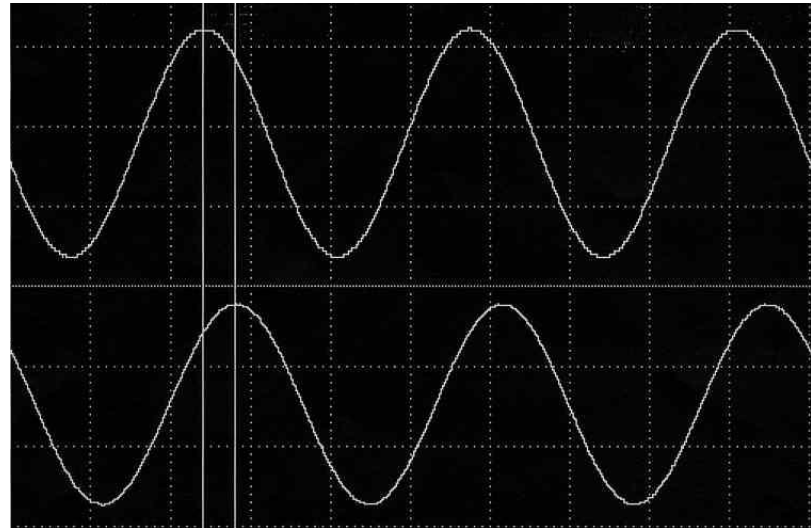


Figure Shows the 1560 nm and port 1 selections giving the desired 800 ps delay.

PROOF-OF-CONCEPT EXPERIMENTAL DEMONSTRATION

Max Delay Obtained: 25.6 ns

Max Number of Delays: 73,142 (> 16 bits Controls)

Max Optical Loss: 4.22 dB

Max. Measured Time Resolution: 0.5 ps (Scope Limit)

Expected Package Size: 3 in (W) x 7 inch (L) x 2 in (H)

TO OUR KNOWLEDGE,
THESE ARE RECORD BREAKING
NUMBERS FOR ANY RF VARIABLE
DELAY LINE

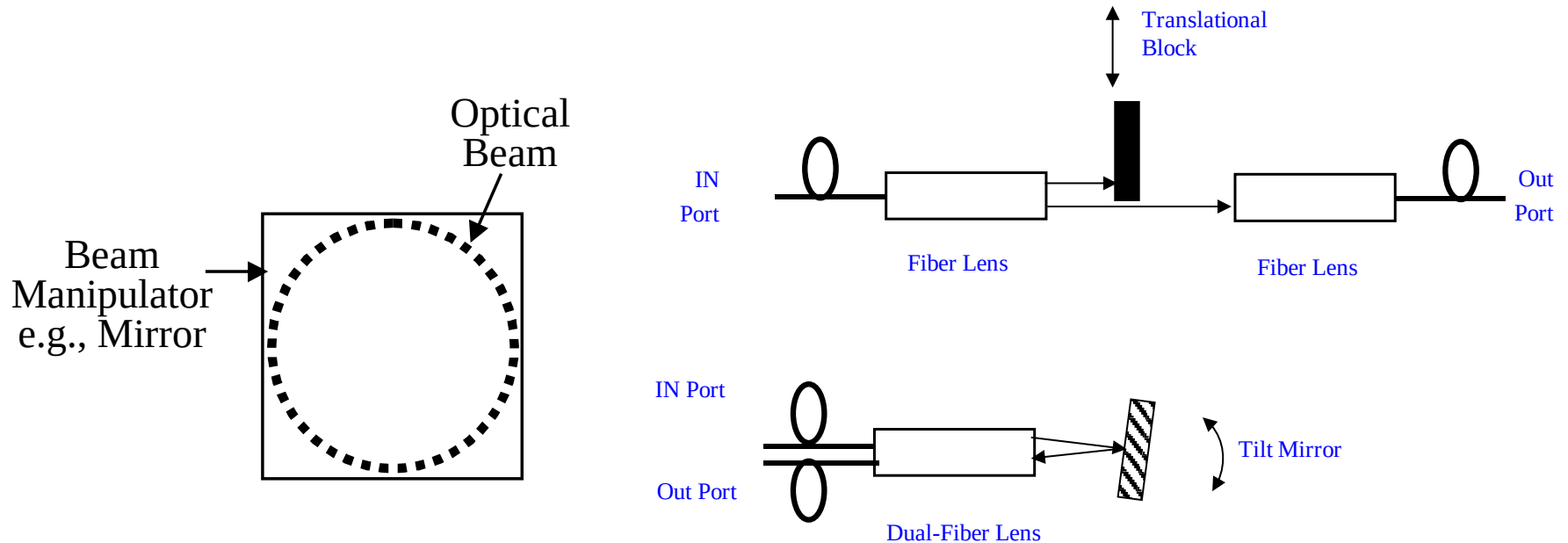
NEED A LOW COST HIGHLY RELIABLE and REPEATABLE VOA WITH SUPER SPECIFICATIONS

What Has Been Tried?

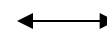


- Mechanical Blocking in Free-Space
- Twisting and Squeezing of Fiber
- Adjust Light Interference
- Vary Absorption Coefficient of Optical Material
- Control Linear Polarization Rotation of Light
- Change Free-Space Coupling of Light between In/Out Ports

Dominant Attenuator Technology used Today: MEMS/Micromirror

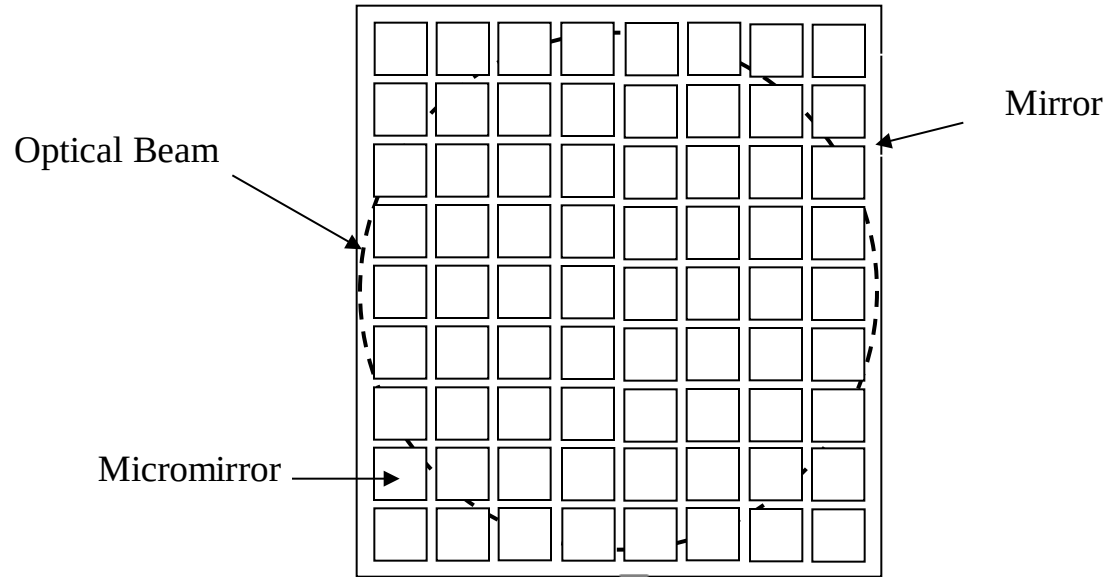


*Requires Super High Precision Analog Motion
of Tilt Mirror or Translation Block to Get
Repeatable High Resolution Controls*



**High Resolution
& High Dynamic
Range Hard to Get
Simultaneously**

Alternate VOA Solution



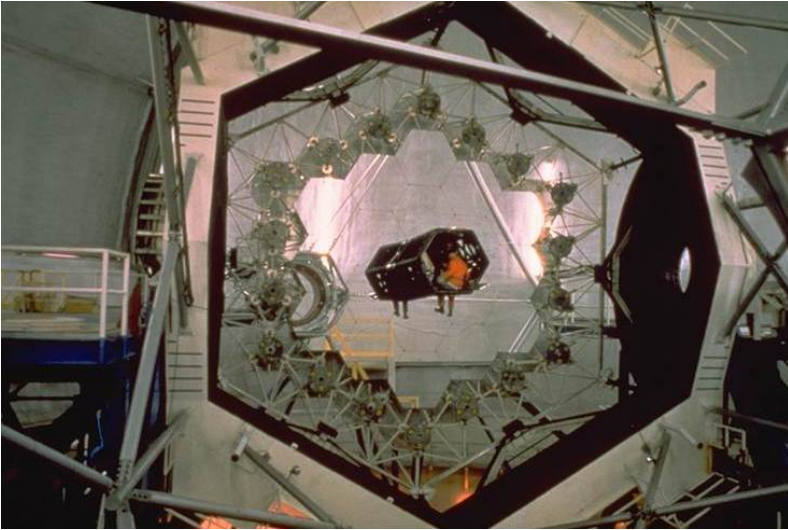
Use a Macro-pixel

Fault Tolerance and High Speed

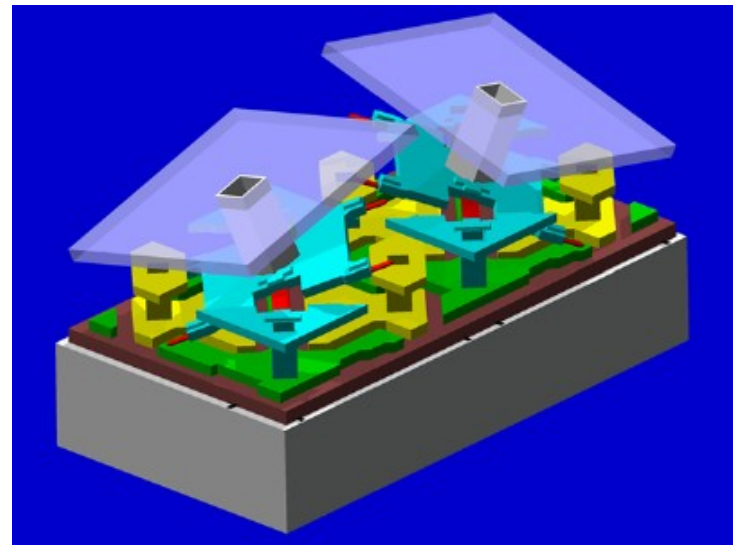
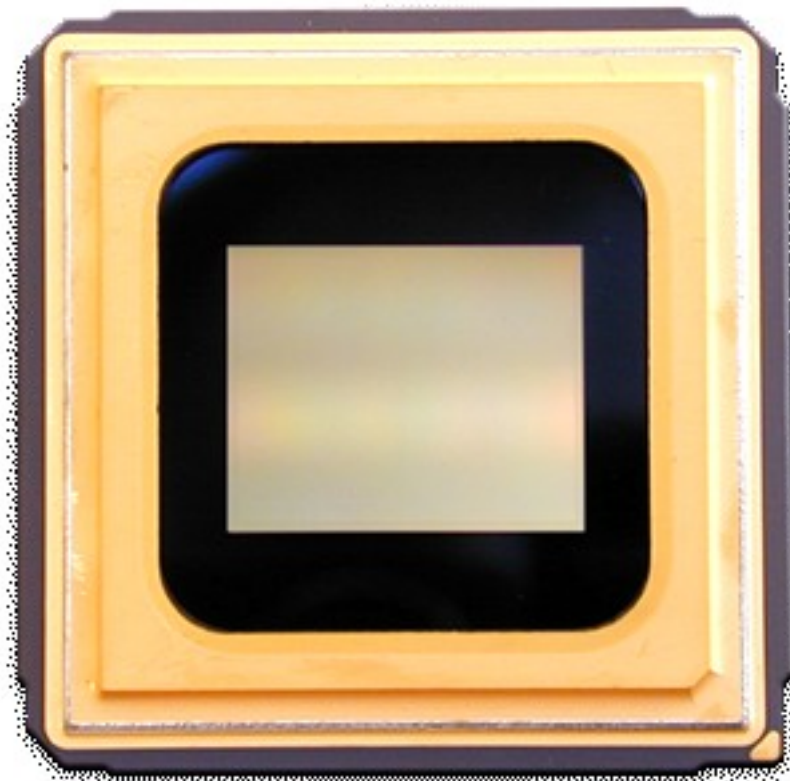
N. A. Riza and S. Sumriddetchkajorn, "Fault-tolerant dense multiwavelength add-drop filter with a two-dimensional digital micromirror device," *Applied Optics*, Vol. 37, No. 27, pp. 6355-6361, 1998.

Modern Day Use of Mirror

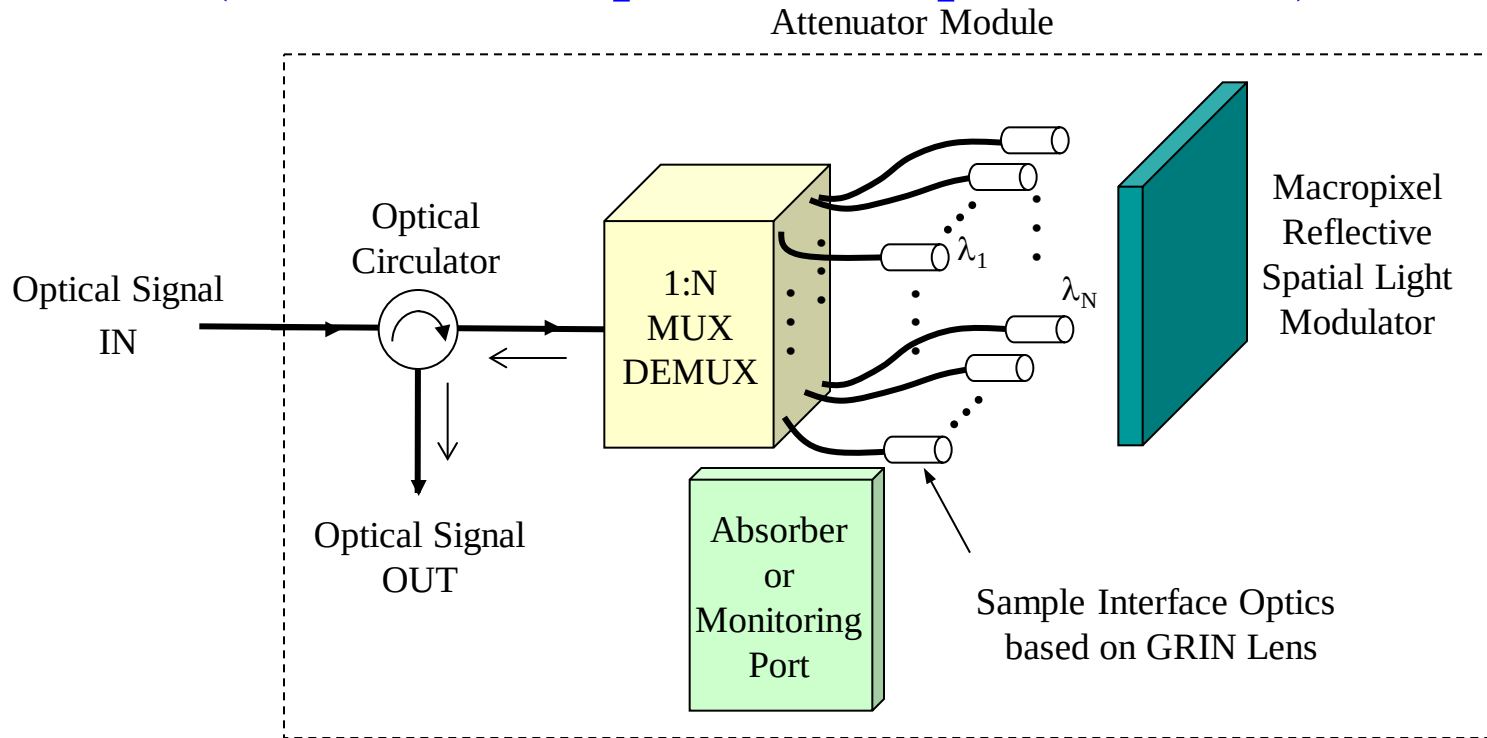
Keck Telescope -- Caltech, UC-Berkeley, and NASA --Mauna Kea, Hawaii.



2-D Micromirror Array Chip Using The Proven DLP™ Technology From Texas Instruments (TI)



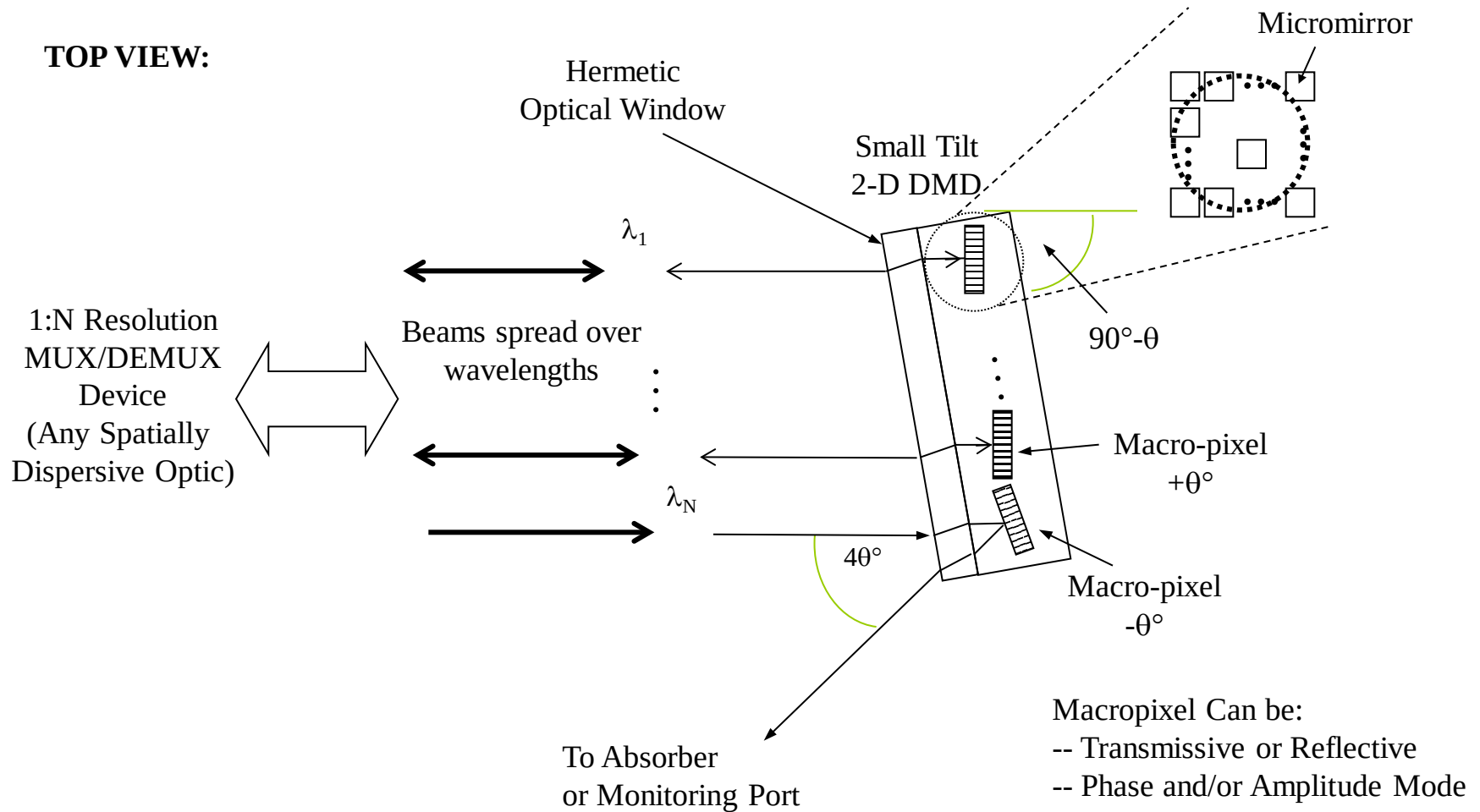
Concept of Macro-pixel and Spatially Multiplexed Multi-Wavelength Attenuation Processing using Beam Spoiling (Via Discrete Spectrum Implementation)



N. A. Riza and Sarun Sumriddetchkajorn, *Optics Letters*, March 1, 1999.

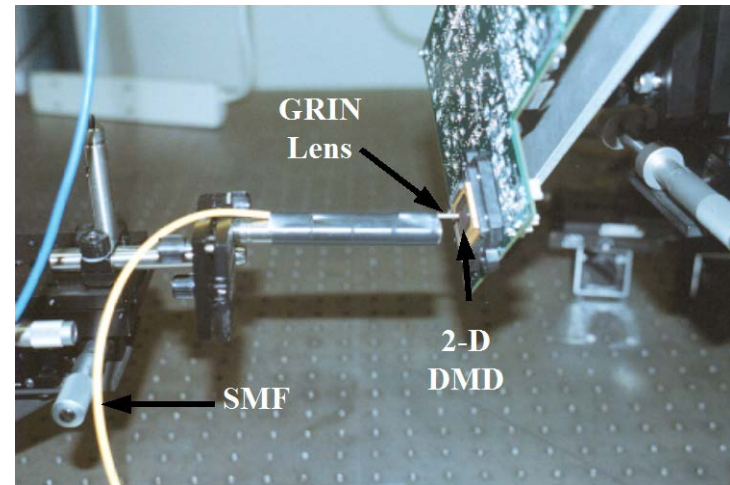
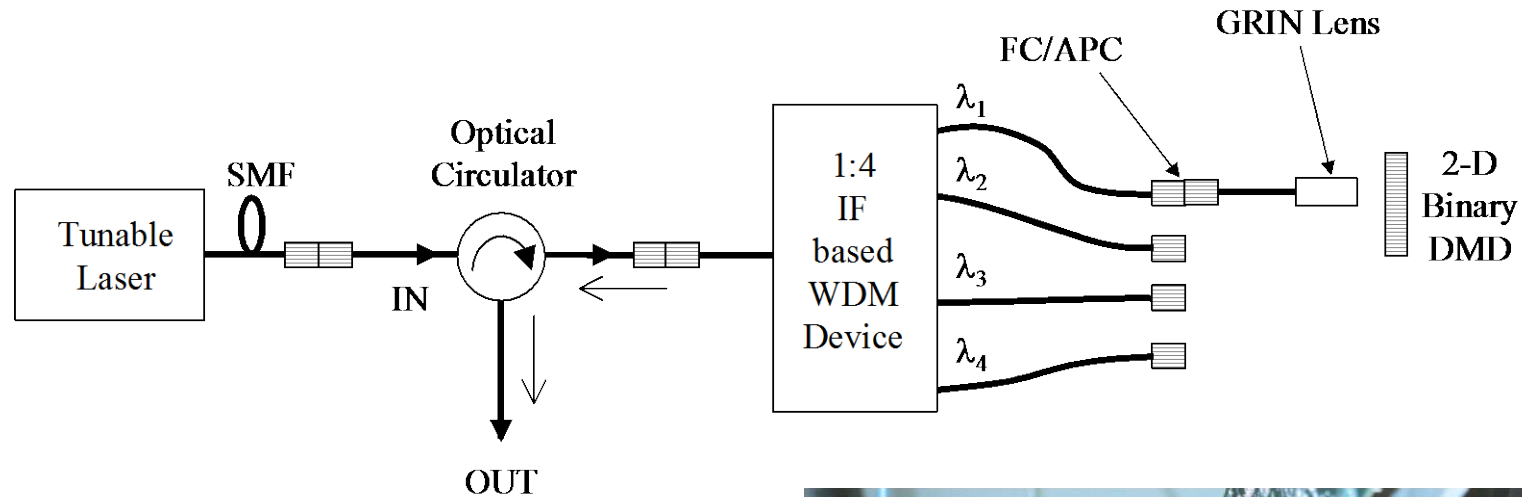
N. A. Riza, Patent No. 6,222,954, April 24, 2001.

Multiwavelength Attenuator Operation With Sample Micromirror Tilt-Mode Macro-pixel

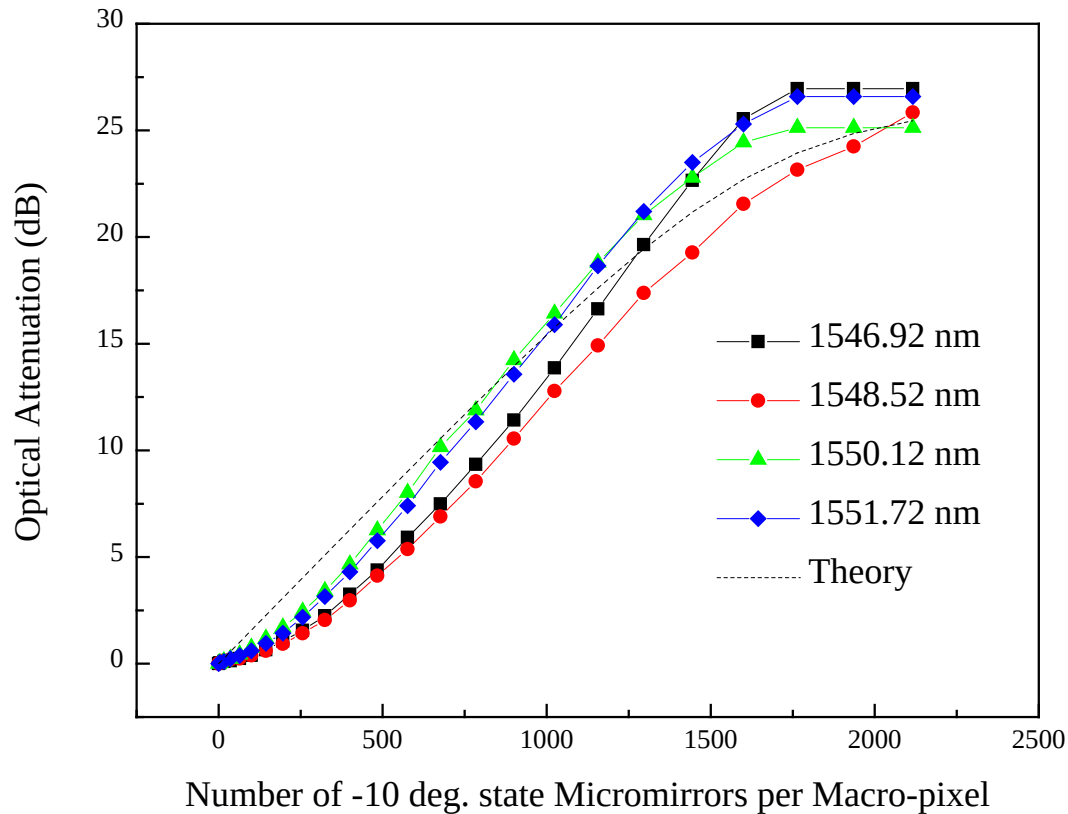


Note: e.g., $\theta=10^\circ$ for TI Visible 2-D DMD

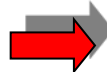
Experimental Setup of Our Retro-Reflective Variable Fiber-Optic Attenuator Using TI 2-D DMD



High-Resolution Optical Attenuator Experimental Results

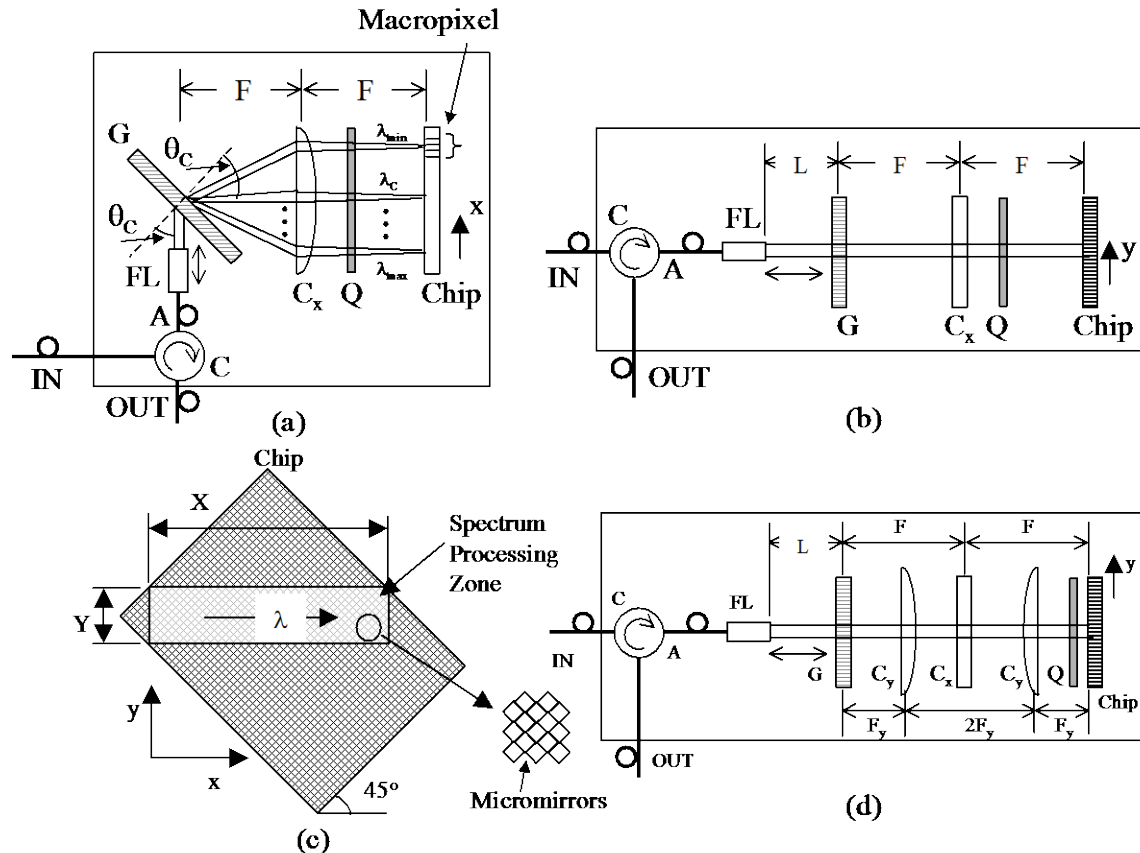


Measured Average Maximum Optical Attenuation  26 dB

For an Optical Beam diameter of 0.97 mm  ~ 2116 Micromirrors in a Macropixel (11-bit Resolution)

 0.011 dB/Micromirror

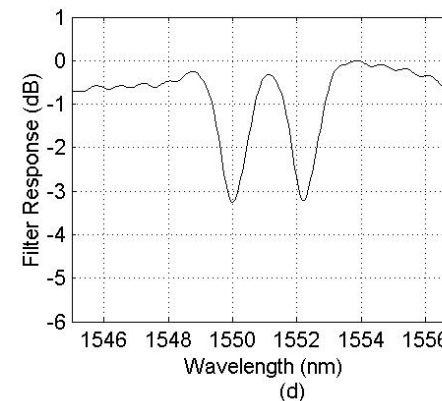
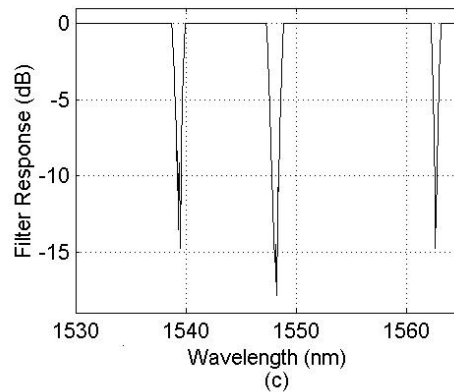
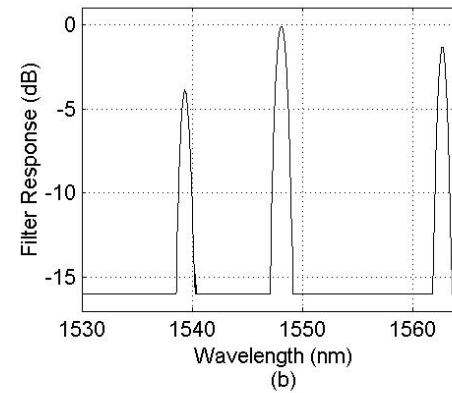
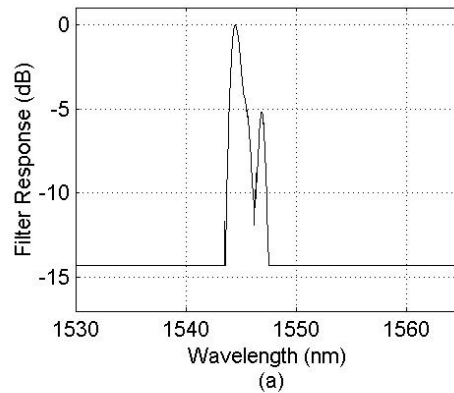
Concept of Macro-pixel and Spatially Multiplexed Multi-Wavelength Attenuation Processing using Beam Spoiling (Via Continuous Spectrum Processing)

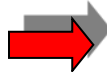


N. A. Riza and M. J. Mughal, *Optics Express*, June 30, 2003.

N. A. Riza, Patent No. 6,222,954, April 24, 2001.

Spectrum Processing Equalizer Results



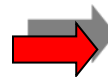
Measured Average Maximum Optical Attenuation  35 dB

Spectrum Processing Zone: 35 nm

Total Insertion Loss: 5.2 dB

3-dB Resolution: 2.24 nm

PDL: < 0.1 dB



13-bit Resolution



0.004 dB/Micromirror

THE GOAL



ACHIEVE SIMULTANEOUSLY SUPER HIGH DYNAMIC RANGE AND
REPEATABLE HIGH RESOLUTION VOA CONTROL

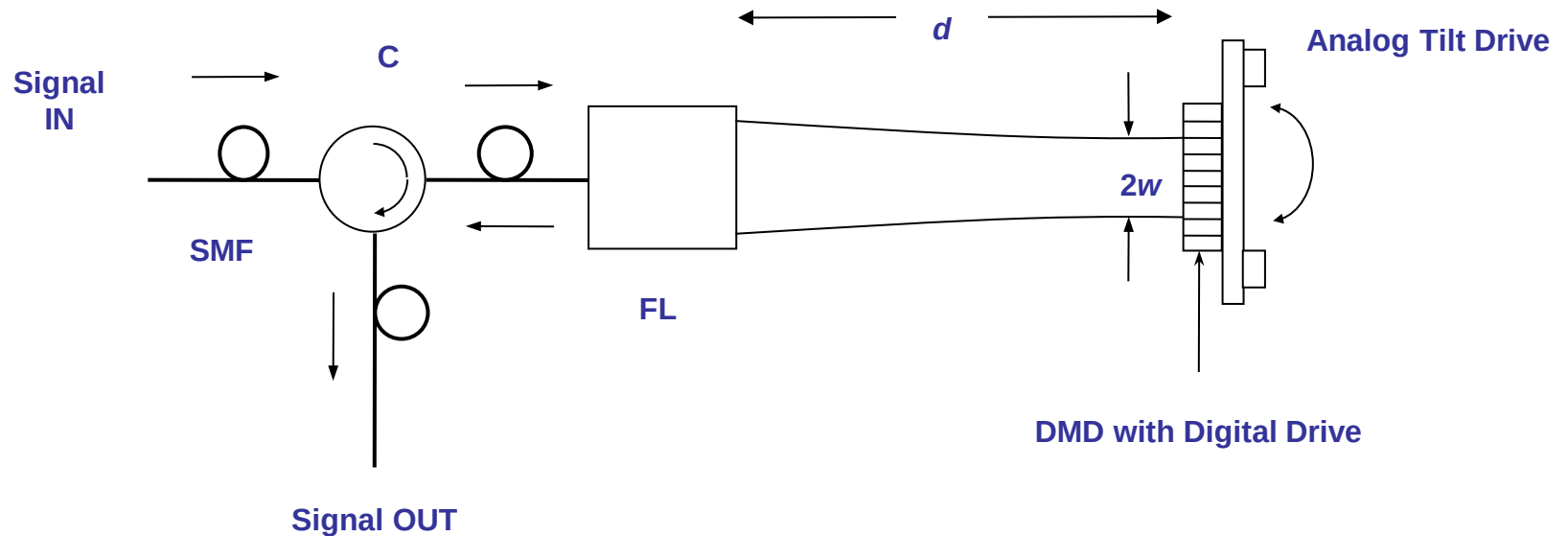


THE NOVEL SOLUTION



THE HYBRID ANALOG-DIGITAL DESIGN VOA
(See N. A. Riza, US Patent 6,563,974, May 13, 2003)

SINGLE FIBER RETRO-REFLECTIVE HYBRID ANALOG-DIGITAL MEMS VOA DESIGN

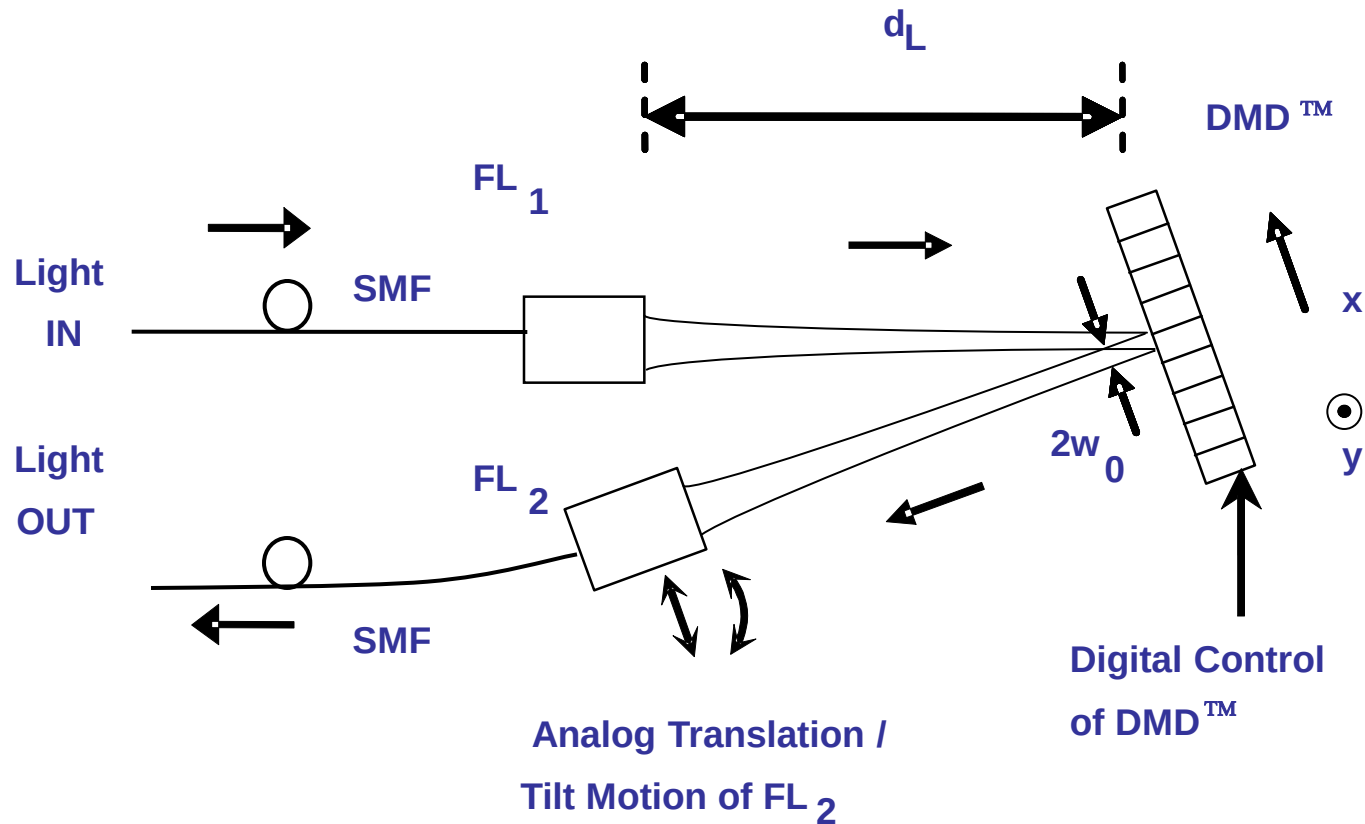


C : Fiber-optical Circulator
DMD™ : Digital Micromirror Device

FL: Self-Imaging Fiber Lens
2w: Beam Waist Diameter

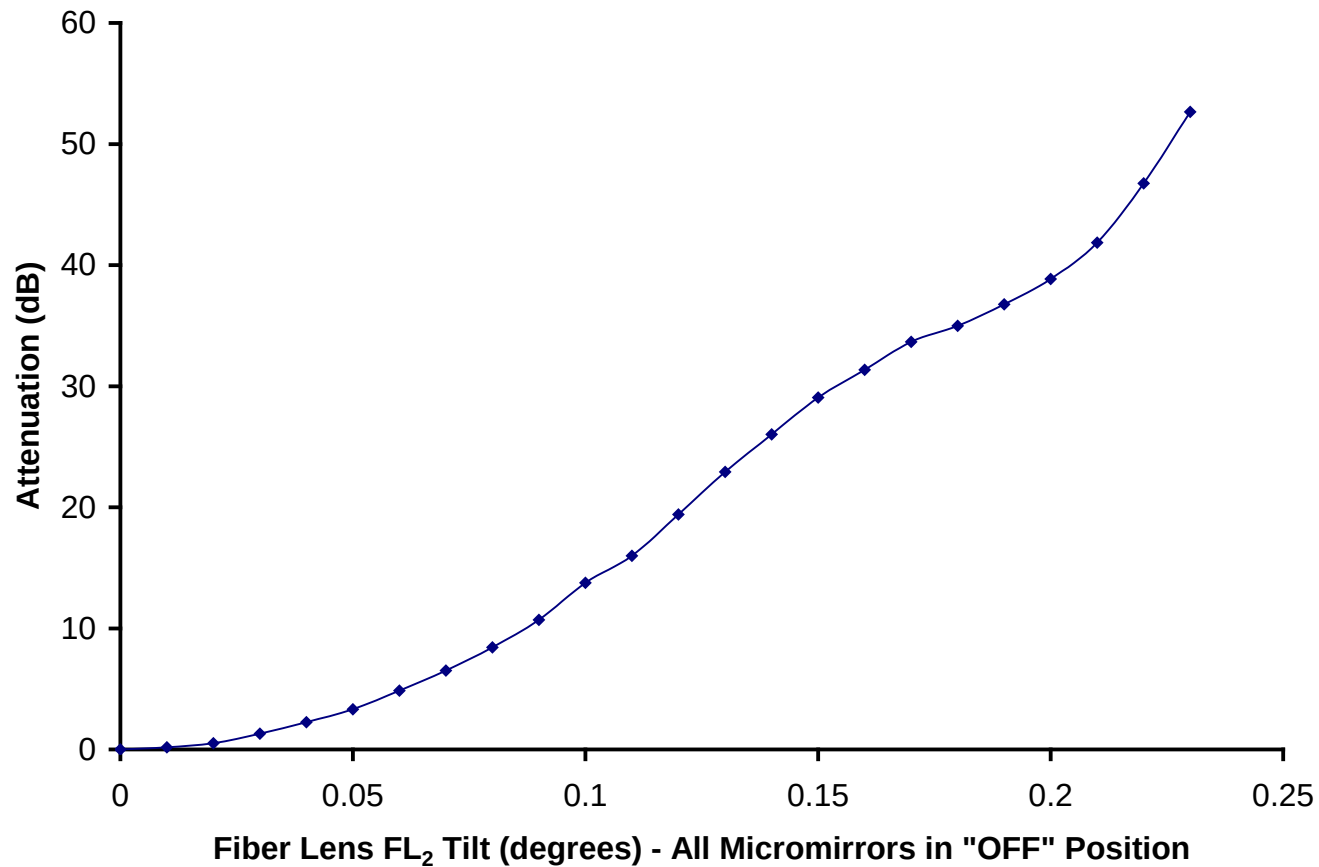
D=6 cm w=0.22 mm

TWO FIBER HYBRID ANALOG-DIGITAL MEMS VOA

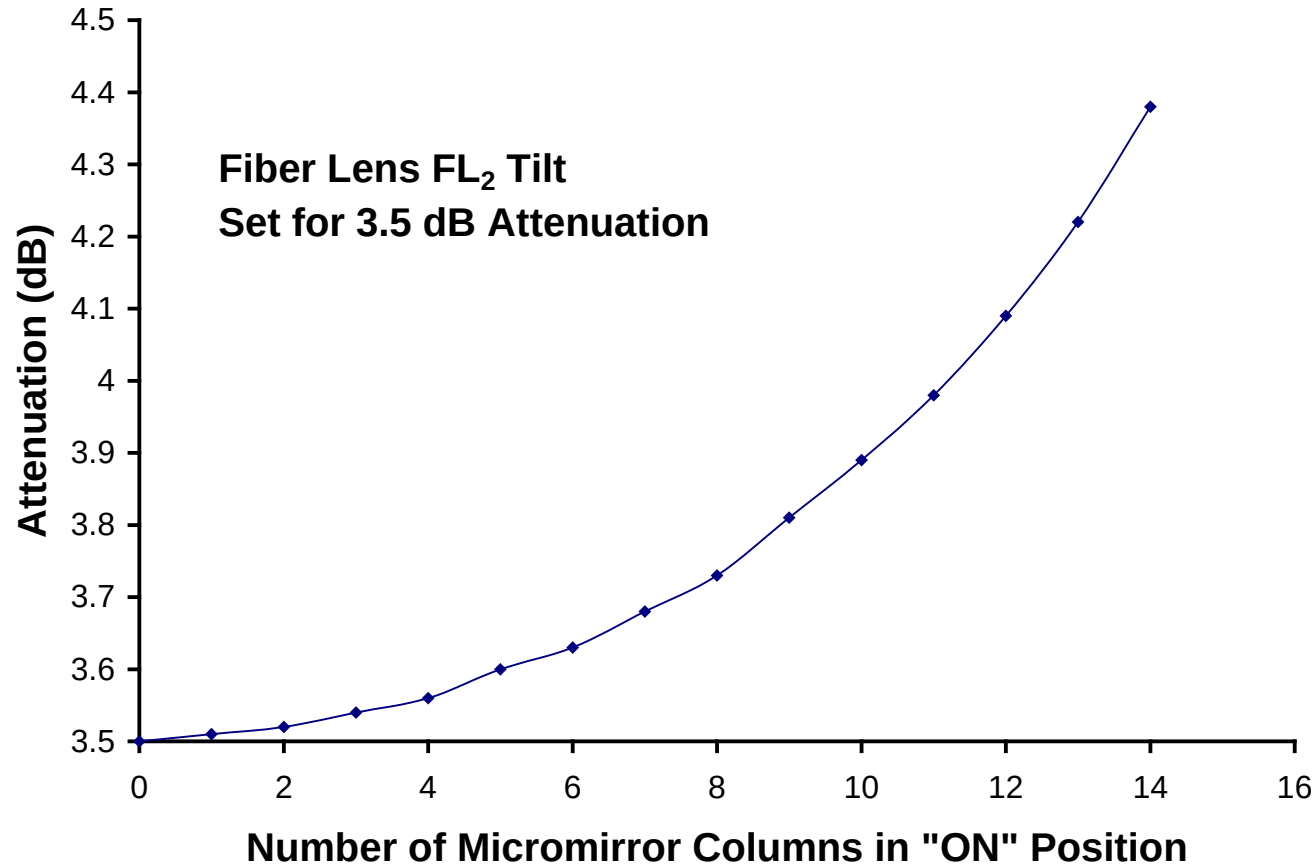


- FL₁/FL₂ : Self-Imaging Fiber Lenses
- 2d_L : Fiber Lens self-imaging distance (or 12 cm)
- 2w₀ : Beam Waist Diameter. (or 0.44 mm)
- DMD™ : Digital Micro-mirror Device;

MEASURED CONTINUOUS 53 DB DYNAMIC RANGE ATTENUATION USING 0.23° TILT-ONLY MOTION OF THE FIBER LENS FL2

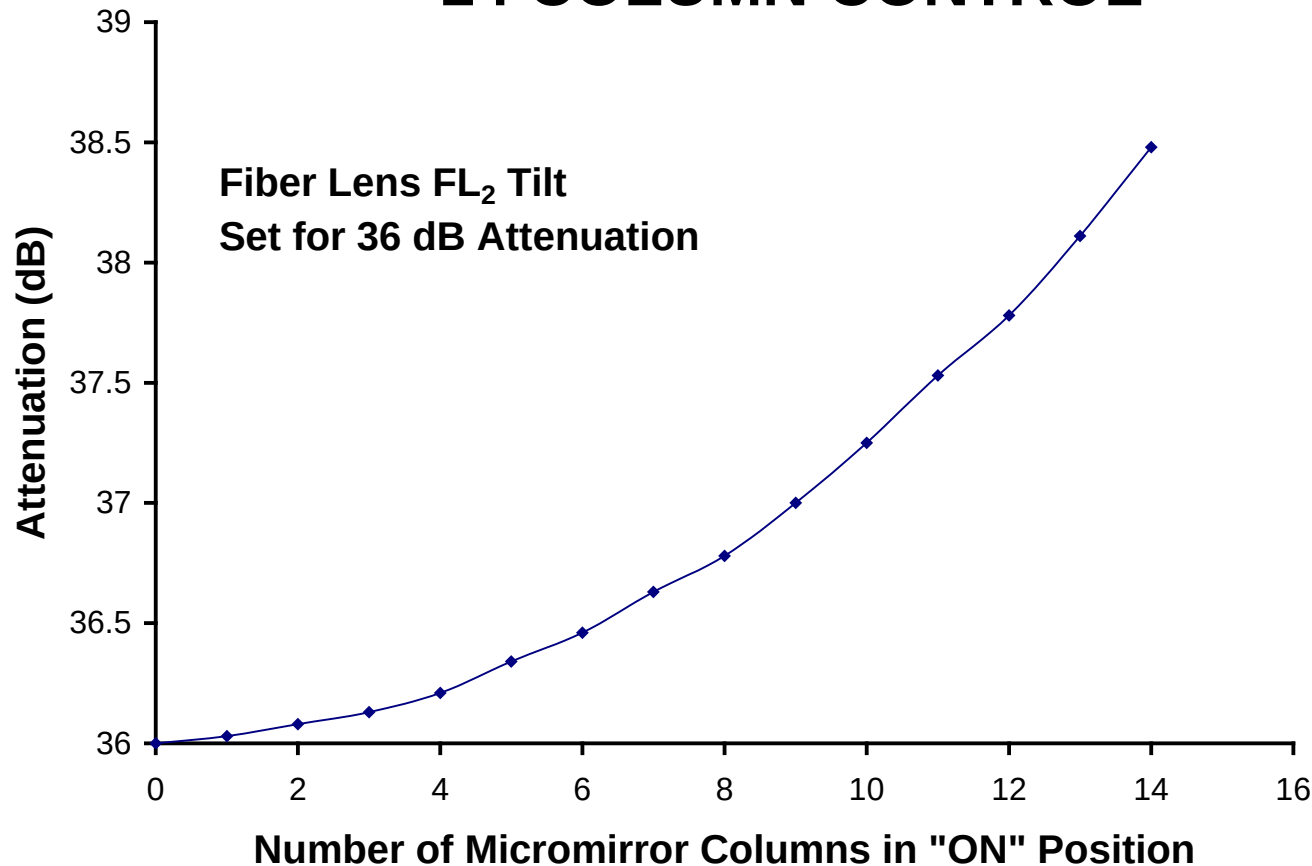


MEASURED DIGITAL ATTENUATION PRODUCED VIA PURE DIGITAL MICRO-MIRROR 14 COLUMN CONTROL



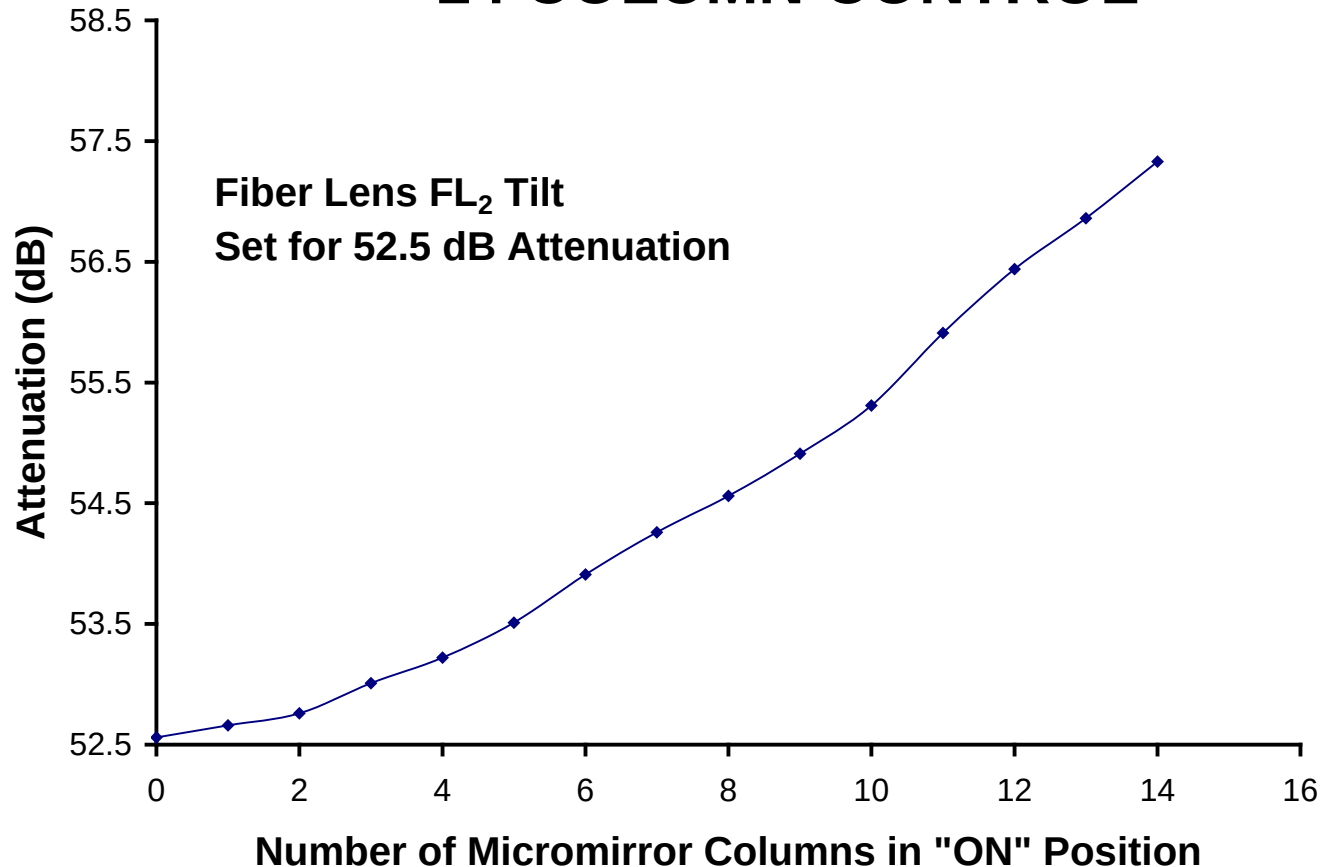
Analog setting of the VOA at 3.5 dB attenuation with an additional 0.88 dB produced by digital control.

MEASURED DIGITAL ATTENUATION PRODUCED VIA PURE DIGITAL MICRO-MIRROR 14 COLUMN CONTROL



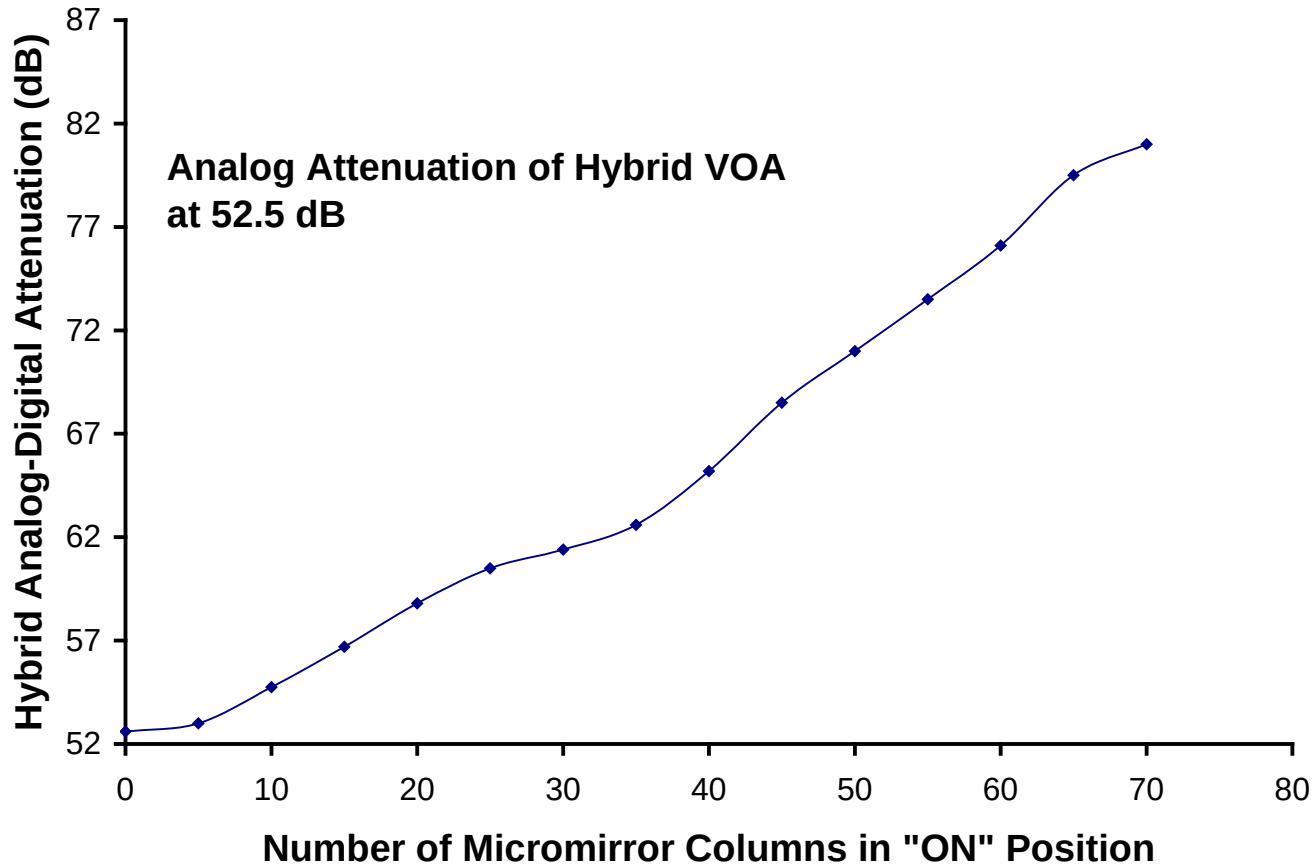
Analog setting of the VOA at 36 dB attenuation with an additional 2.48 dB produced by digital control.

MEASURED DIGITAL ATTENUATION PRODUCED VIA PURE DIGITAL MICRO-MIRROR 14 COLUMN CONTROL



Analog setting of the VOA at 52.5 dB attenuation with an additional 4.36 dB produced by digital control.

HYBRID ANALOG-DIGITAL ATTENUATION CONTROLS FOR SUPER HIGH DYNAMIC RANGE



Analogue attenuation of 52.5 dB and 70 digital micro-mirror column control of the DMD™ gives a combined super high dynamic range of 81 dB.

TWO FIBER HYBRID MEMS VOA SUMMARY

- Fiber-to-Fiber insertion Loss: 2.25 dB
- Hybrid Dynamic Range: 81.5 dB
- Resolution: 0.1 dB (measured)
- Super Resolution: <0.0035 dB (capability using single micro-mirror)
- PDL: 0.05 dB
- Test Wavelength Band : C Band: 1530-1565 nm
- Speed: 1 ms DMD Digital Reset + Fiber Lens Tilt Motion

Future Work: Packaging and Calibration (Look-up Table)

[Super High Dynamic Range Demonstration](#)

Overall Conclusions

A Fundamental Change has been Introduced in Design of
Photonic Signal Processors



The Hybrid Analog-Digital Design

- Experimentally Demonstrated Hybrid VOA shows Both
Super High Dynamic Range (> 81 dB) and High Resolution (< 0.1 dB)
Repeatable Performance
- Experimentally Demonstrated Hybrid Optical Delay Line that shows Both
Super Long Delay Range (> 25 ns) and High Resolution (< 0.35 ps)
Repeatable Performance

Generalized RF Transversal Filter

Time Domain output of a generalized Transversal Filter

$$r(t) = \sum_{n=0}^{N-1} A_n s(t - n\tau)$$

where A_n is the weight of the n th component of the input signal $s(t)$ and τ is a time delay step generated in the filter structure.

Impulse Response of the generalized Transversal Filter

$$h(t) = \sum_{n=0}^{N-1} A_n \delta(t - n\tau)$$

Frequency Response of the generalized Transversal Filter

$$H(f) = \mathfrak{F} \left\{ \sum_{n=0}^{N-1} A_n \delta(t - n\tau) \right\}$$

where the operator $\mathfrak{F}$ represents the Fourier Transform.

FIR filter implementation through window functions

- Improve filter characteristics.
- Rectangular, Hamming, Triangular, Bartlett, Blackman, Keiser, Reimann etc.

Two Tap RF Transversal Notch Filter using Rectangular Window

Two Tap Notch Filter Output

$$r(t) = \sum_{n=0}^1 A s(t - n\tau) = A[s(t) + s(t - \tau)]$$

Time Domain Impulse Response

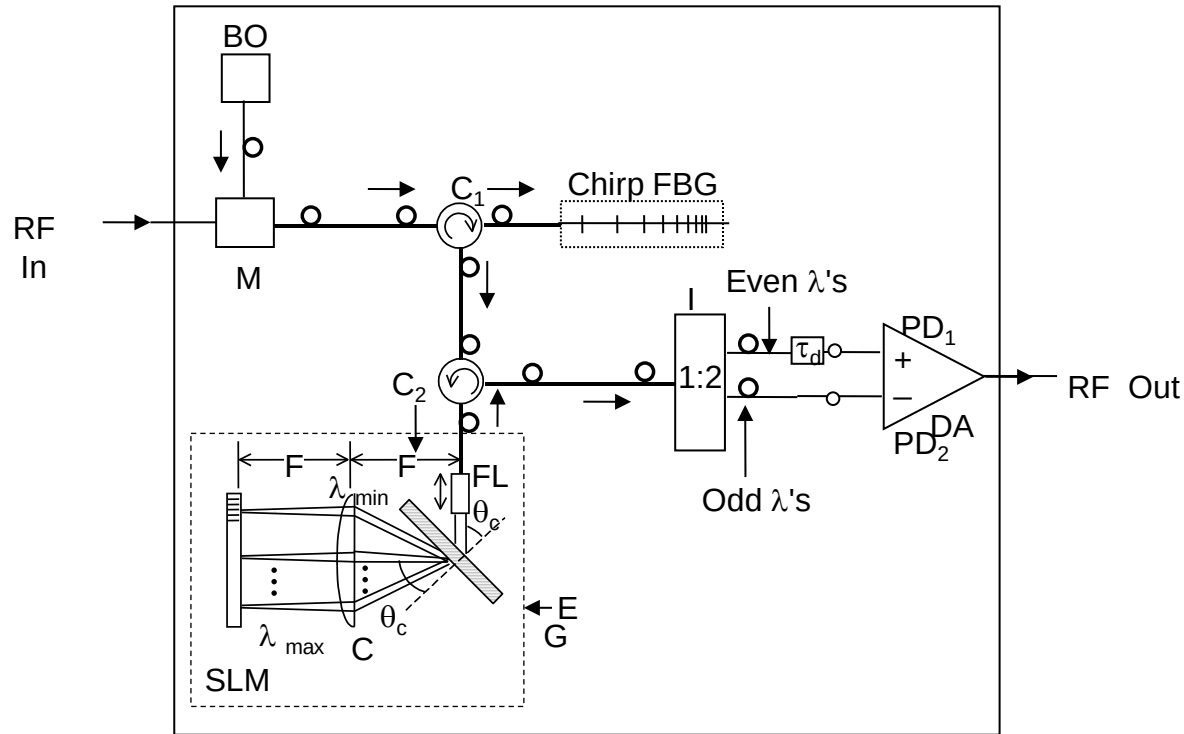
$$h(t') = A[\delta(t' + \tau / 2) + \delta(t' - \tau / 2)]$$

Frequency Domain Impulse Response

$$H(f) = 2A \cos(\pi f \tau)$$

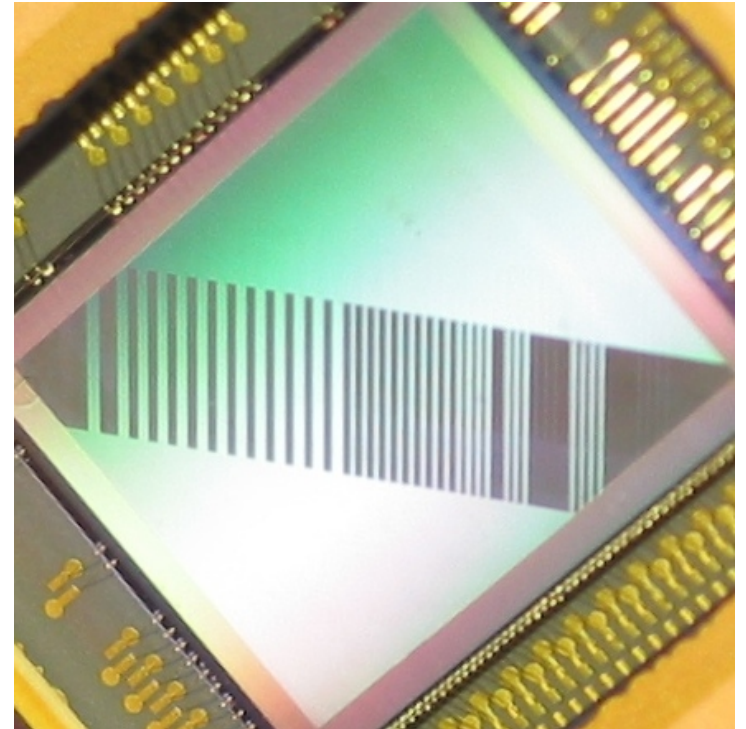
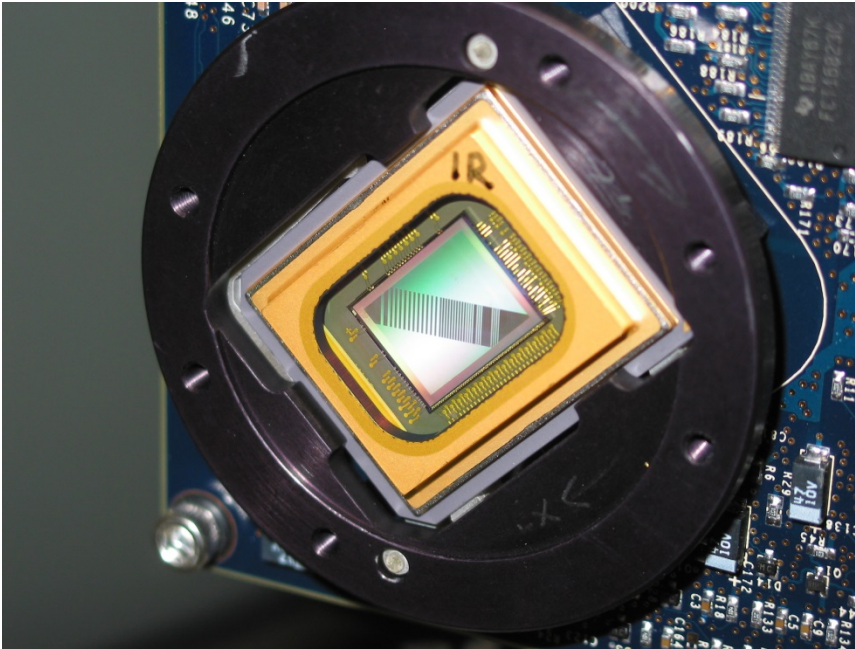
$H(f)=0$ or a null for the RF frequencies occurs at $f_{null} = (2k+1)f_0$, where $f_0=1/2\tau$.

RF WIDEBAND TRANSVERSAL FILTER USING OPTICS

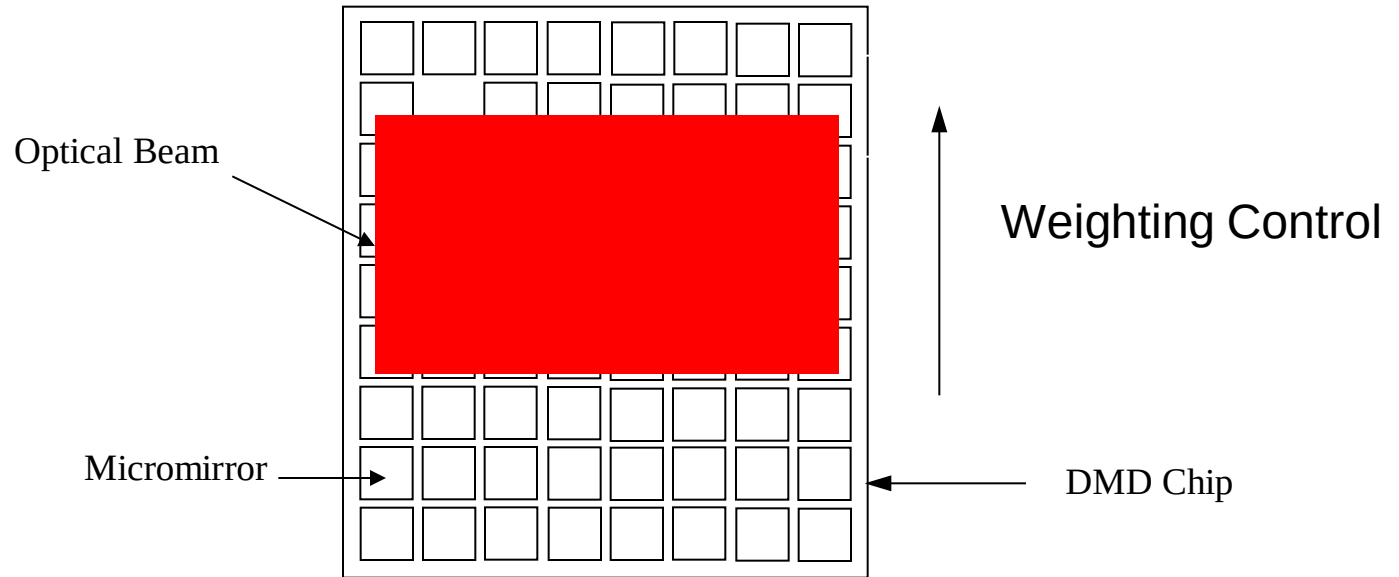


SLM: Spatial Light Modulator (SLM) such as a DMD; M: High Speed Optical Intensity Modulator, BOS: Broadband Optical Source, τ_d : Fixed Path optical delay between odd and even wavelengths of the Interleaver, I: Interleaver, DA: Differential Amplifier, E: Equalizer Optics, C1, C2: Optical circulators, G: Grating, C: Cylindrical lens, PD1, PD2: Photodetectors, θ_c : Grating Bragg Angle, F: Focal Length of C.

2-D SLM DMD Chip



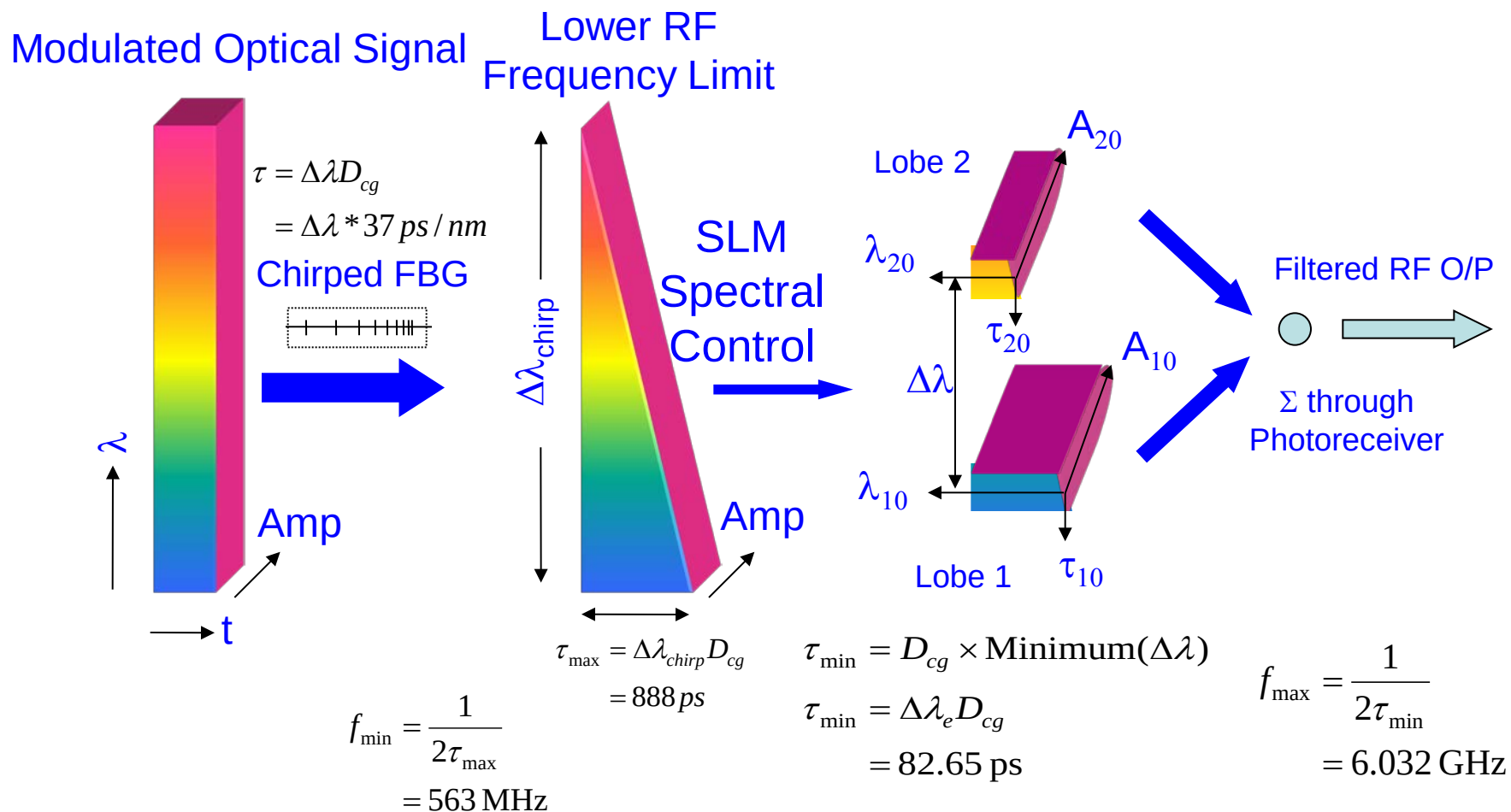
2-D SLM DMD Chip Operation



Time Delay Control (Tap Selection)

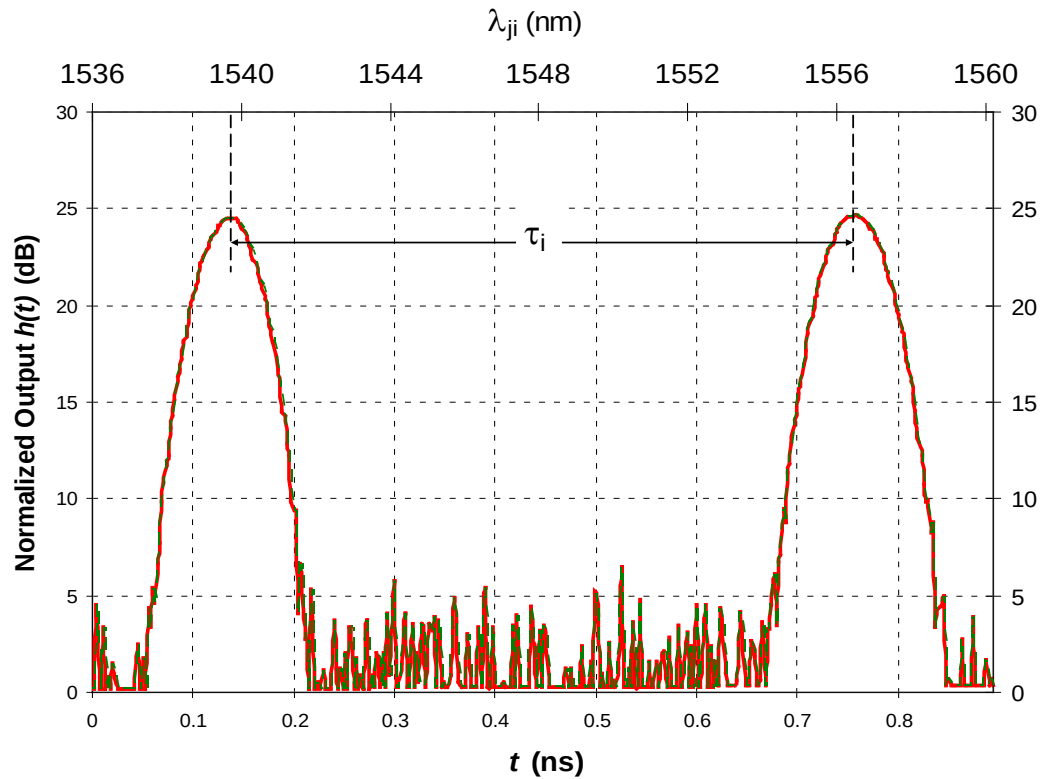
$$\begin{aligned}\tau &= \Delta\lambda D_{cg} \\ &= \Delta\lambda * 37 \text{ ps / nm}\end{aligned}$$

Two-Tap Notch Filter Example



Experimental Demonstration of Two-Tap Notch Filter

Time Domain Impulse Response



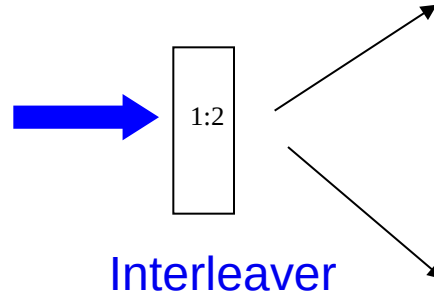
Time domain impulse response $h(t)$ of the demonstrated RF notch filter generated via the OSA where the upper x-axis is the λ_{ji} wavelength axis and the lower x-axis is the mapped time delay axis t .

Interleaver Operation

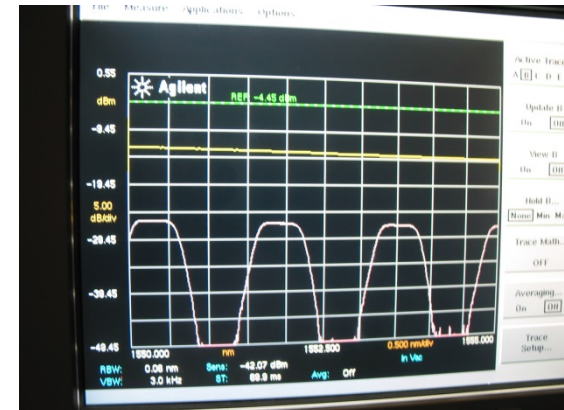


Original Optical Spectrum

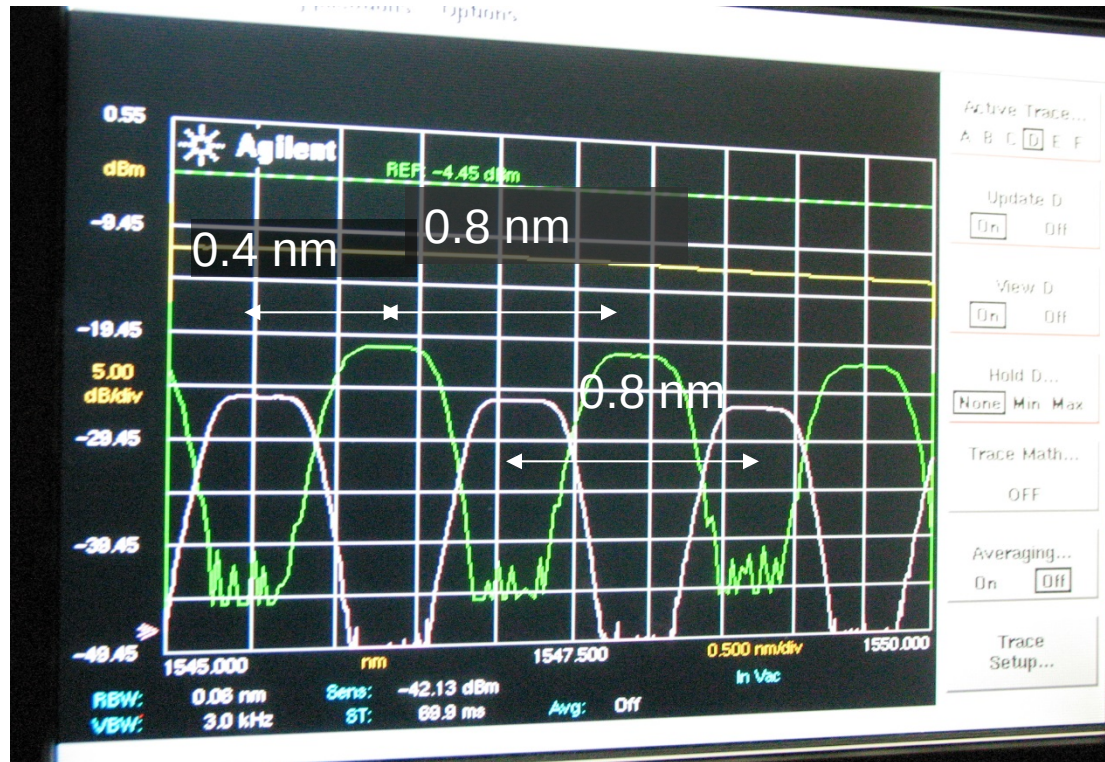
Separation of Odd and Even Wavelengths



Interleaver



Interleaver Operation



Inter-Channel Wavelength Offset = 0.4 nm $\longrightarrow$ 50 GHz Spacing

Same Channel Wavelength Offset = 0.8 nm $\longrightarrow$ 100 GHz Spacing

Advantage of Interleaver in the Proposed Filter



Large Number of Taps

Wavelength Resolution of 0.4 nm

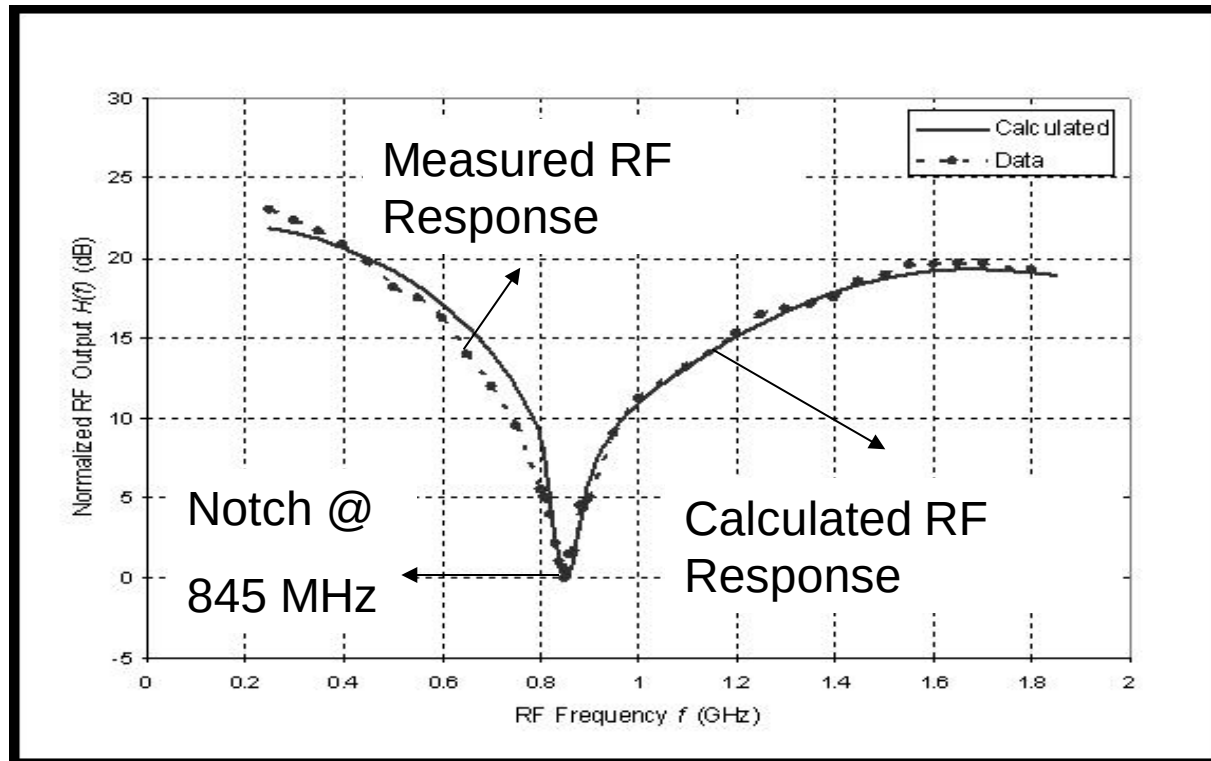
Automatic Wavelength Attenuation



High Frequency
Operation
(33 GHz)



Notch Filter Response



Measure Optical
Spectrum

$$\tau = \Delta\lambda D_{cg}$$

Time Domain

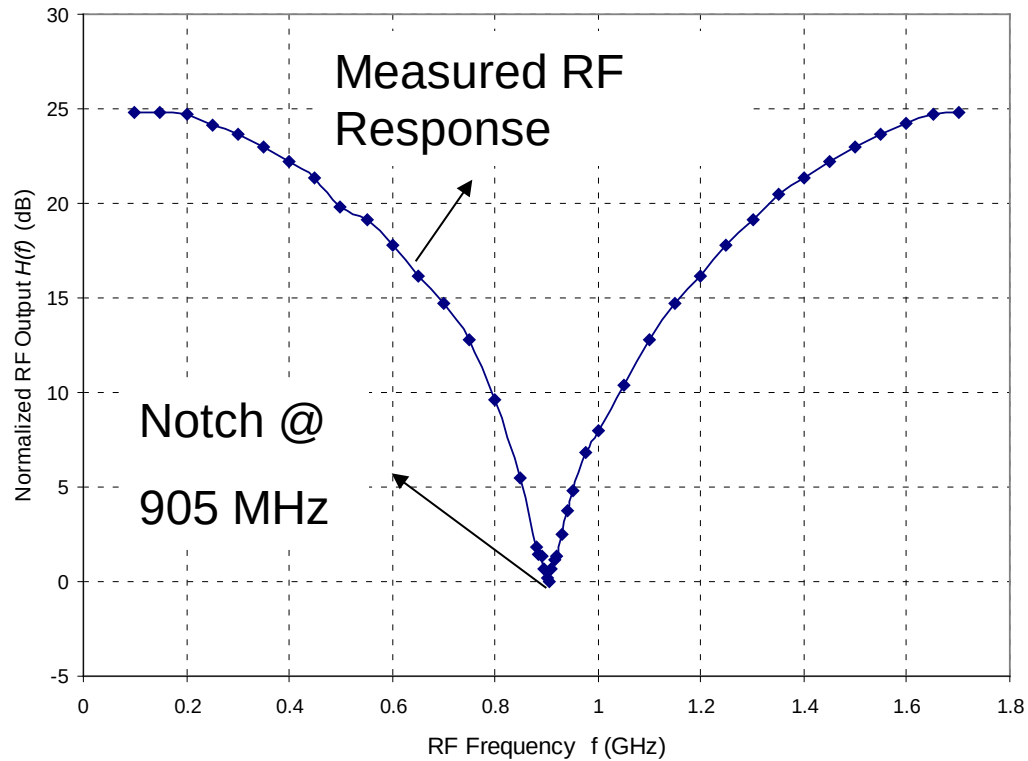
Impulse Response

Fast Fourier
Transform

Frequency Domain

Impulse Response

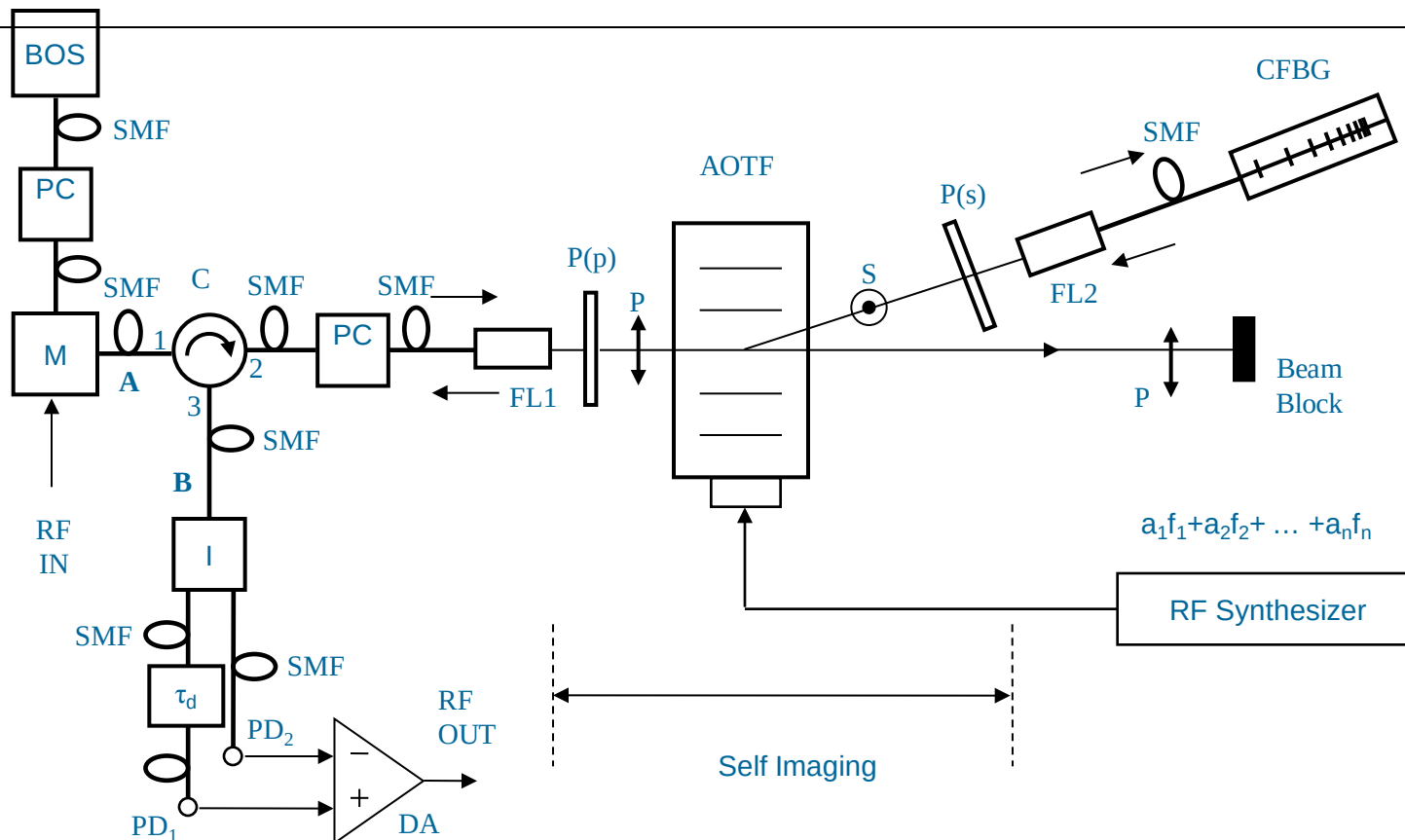
Tunability of the Demonstrated Filter



Demonstrated Features of the Multi-Tap Filter

- 50 dB RF Notch Depth
- 6.2 dB Optical Loss
- 0.5 GHz – 33 GHz Bandwidth
- 13 Tap Positive and Negative Tap Filter
- High Speed Operation

Analog RF Transversal Filter Design using Acousto-Optic Tunable Filter (AOTF)

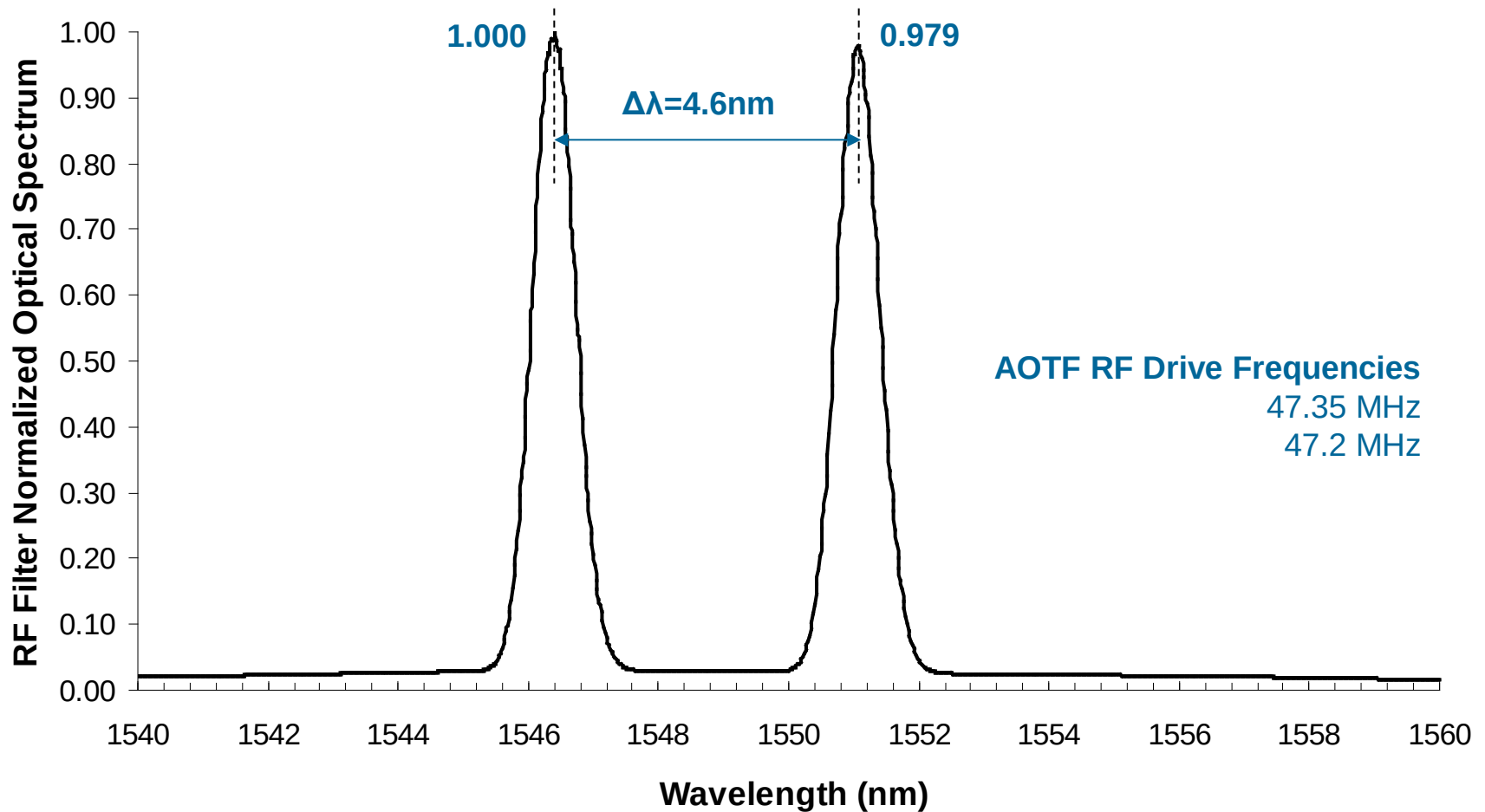


Retro-reflective design programmable broadband RF transversal filter using compact chirped-Fiber Bragg Grating (CFBG) fiber-optics and an AOTF. M: High Speed Optical Intensity Modulator, BOS: Broadband Optical Source, τ_d : Fixed Path optical delay between odd and even wavelengths of the Interleaver, I: Interleaver, DA: Differential Amplifier, C: Optical circulator, PD₁, PD₂: Photodetectors, FL1, FL2: Fiber Lens.

Nabeel Riza and Farzan Ghauri, "Compact Tunable Microwave Filtering using Retro-Reflective Acousto-Optic Tunable Filtering and Delay Controls," accepted for publication in *Applied Optics*, manuscript # 73743.

Experimental Demonstration of Two-Tap Notch Filter

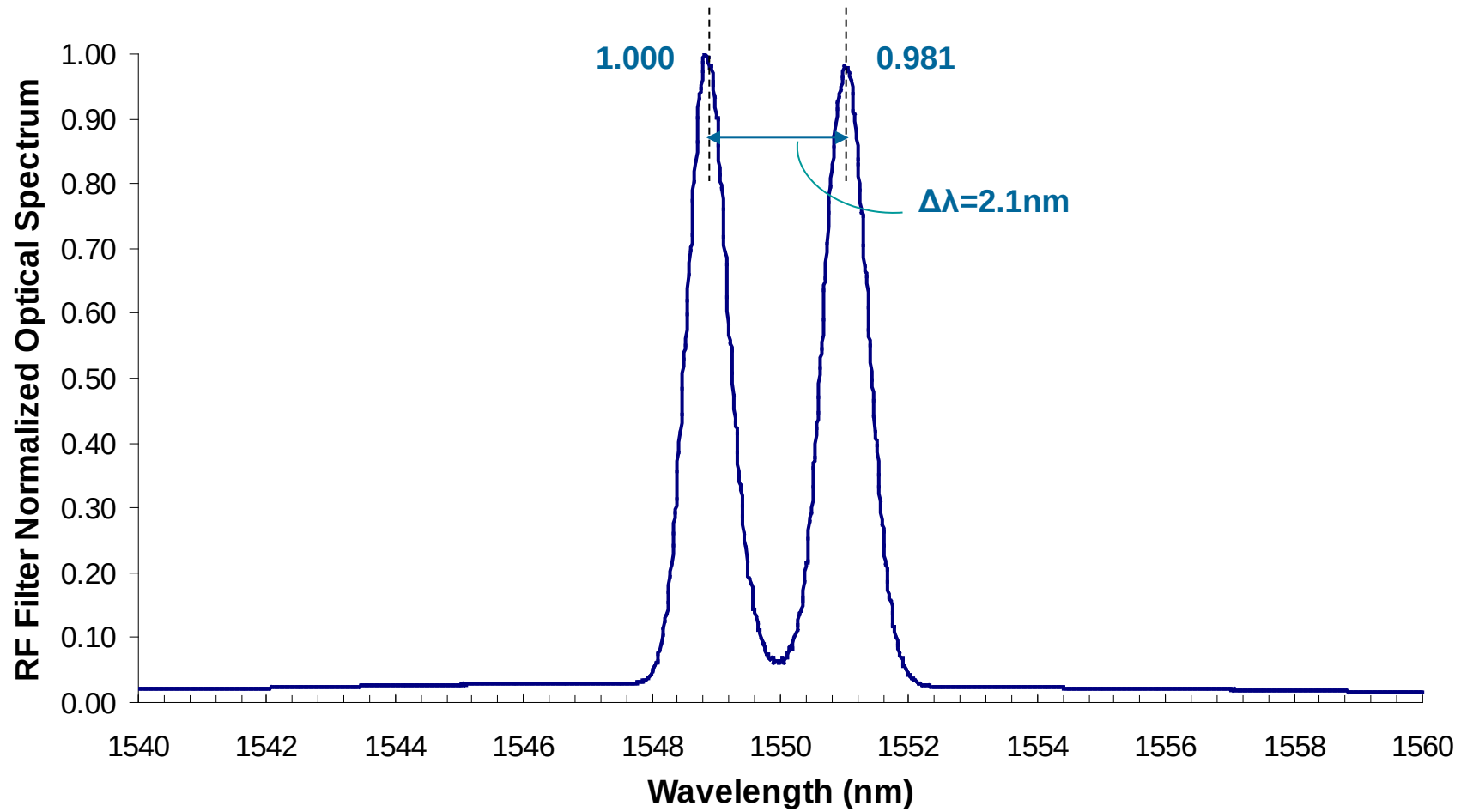
Time Domain Impulse Response



Time domain impulse response $h(t)$ of the demonstrated RF notch filter generated via the OSA where the x-axis is the λ_{ji} wavelength axis equivalent to mapped time delay axis t .

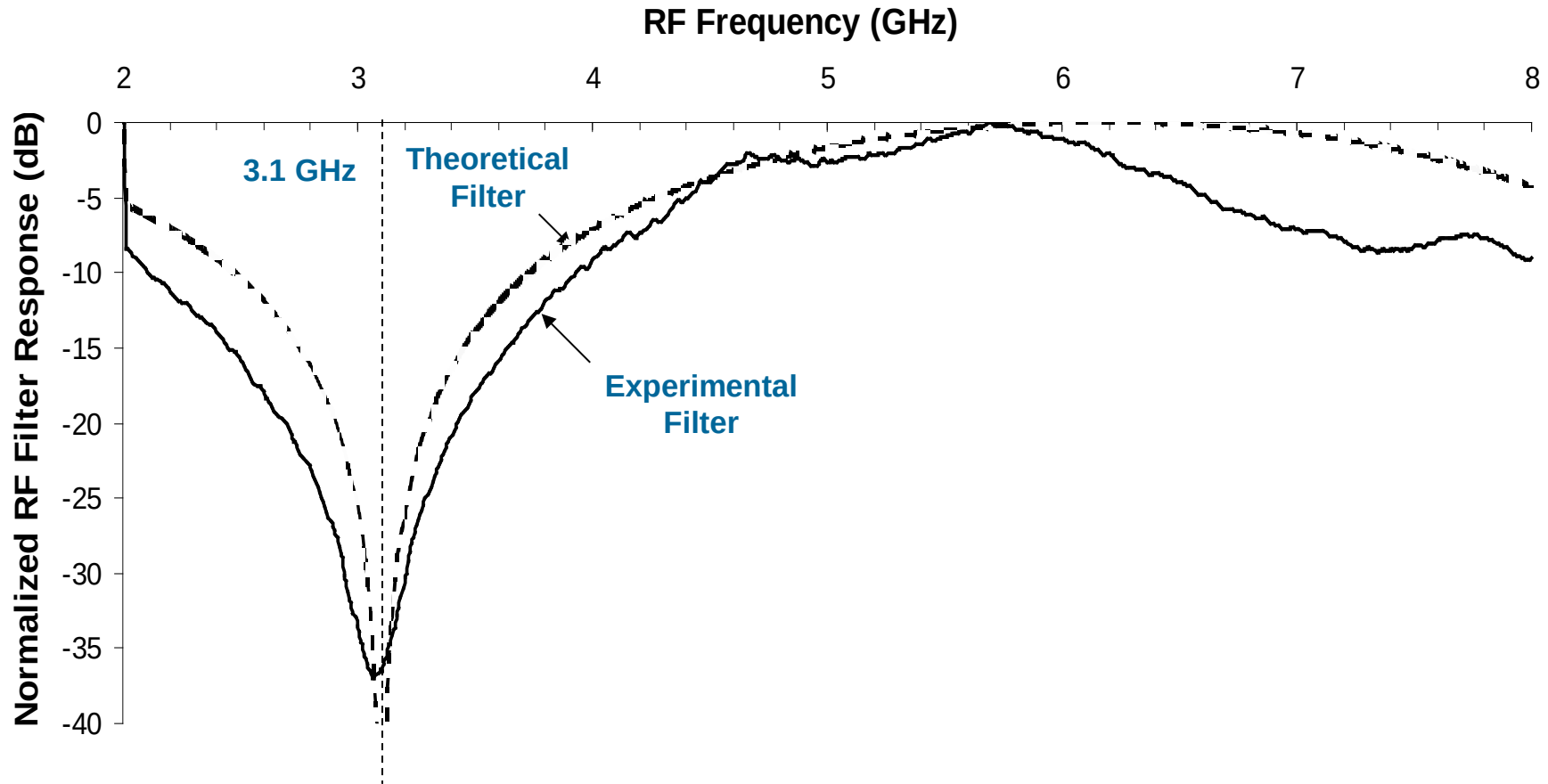
Experimental Demonstration of Two-Tap Notch Filter

Time Domain Impulse Response



Time domain impulse response $h(t)$ of the demonstrated RF notch filter generated via the OSA where the x-axis is the λ_{ji} wavelength axis equivalent to mapped time delay axis t .

Frequency Domain Impulse Response - Tunability of the Demonstrated 2-Tap Filter Notch



$$\tau = \Delta\lambda D_{cg}$$

$$\tau = \Delta\lambda * 35.2 \text{ ps / nm}$$

$$f_{null} = (2k + 1) f_0$$

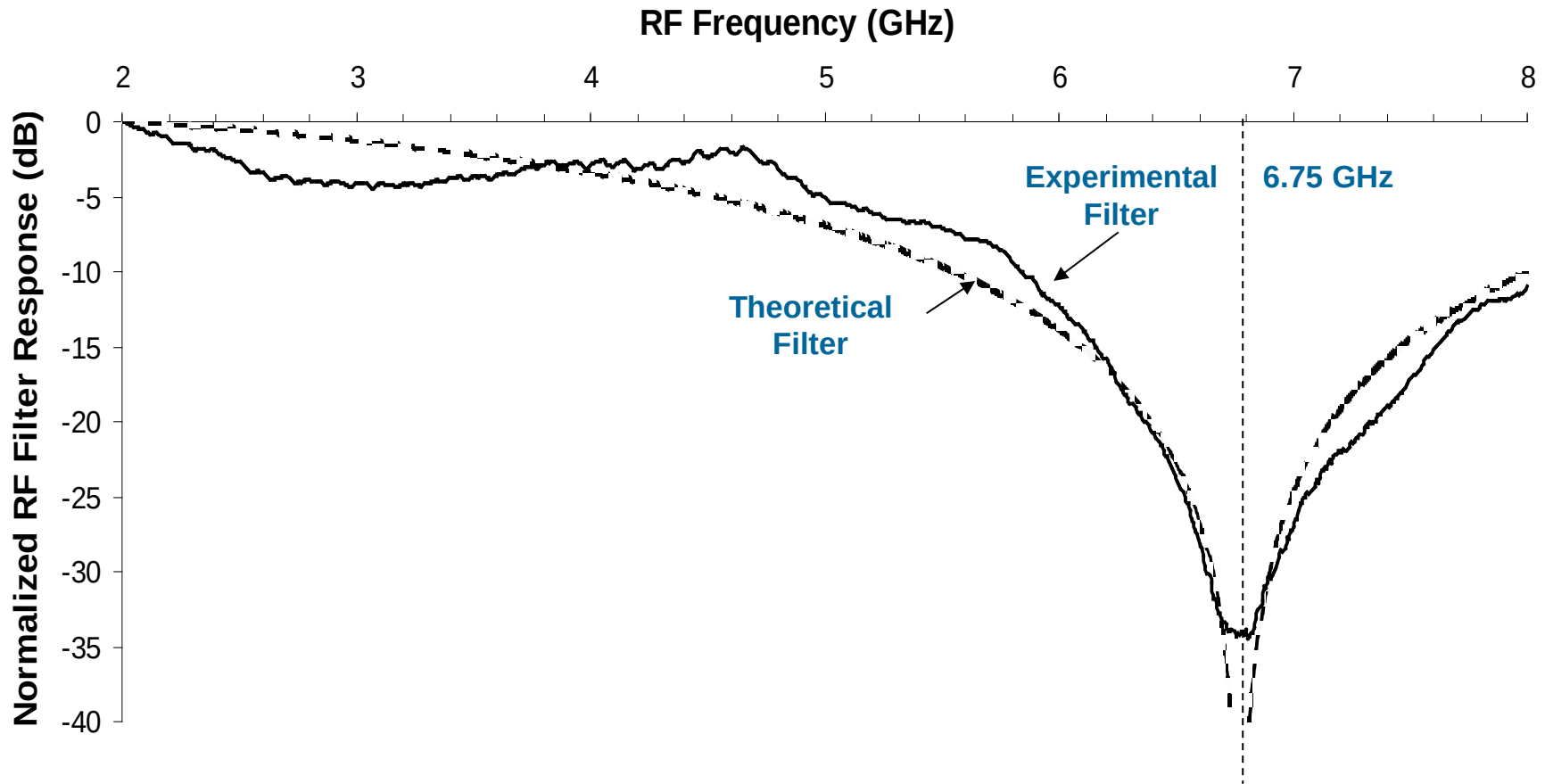
$$f_0 = \frac{1}{2\tau}$$

$$\Delta\lambda = 4.6 \text{ nm}$$

$$\tau = 161.92 \text{ psec}$$

$$f_{null} = 3.1 \text{ GHz}$$

Frequency Domain Impulse Response - Tunability of the Demonstrated 2-Tap Filter Notch



$$\tau = \Delta\lambda D_{cg}$$

$$\tau = \Delta\lambda * 35.2 \text{ ps/nm}$$

$$f_{null} = (2k + 1) f_0$$

$$f_0 = \frac{1}{2\tau}$$

$$\Delta\lambda = 2.1 \text{ nm}$$

$$\tau = 73.9 \text{ psec}$$

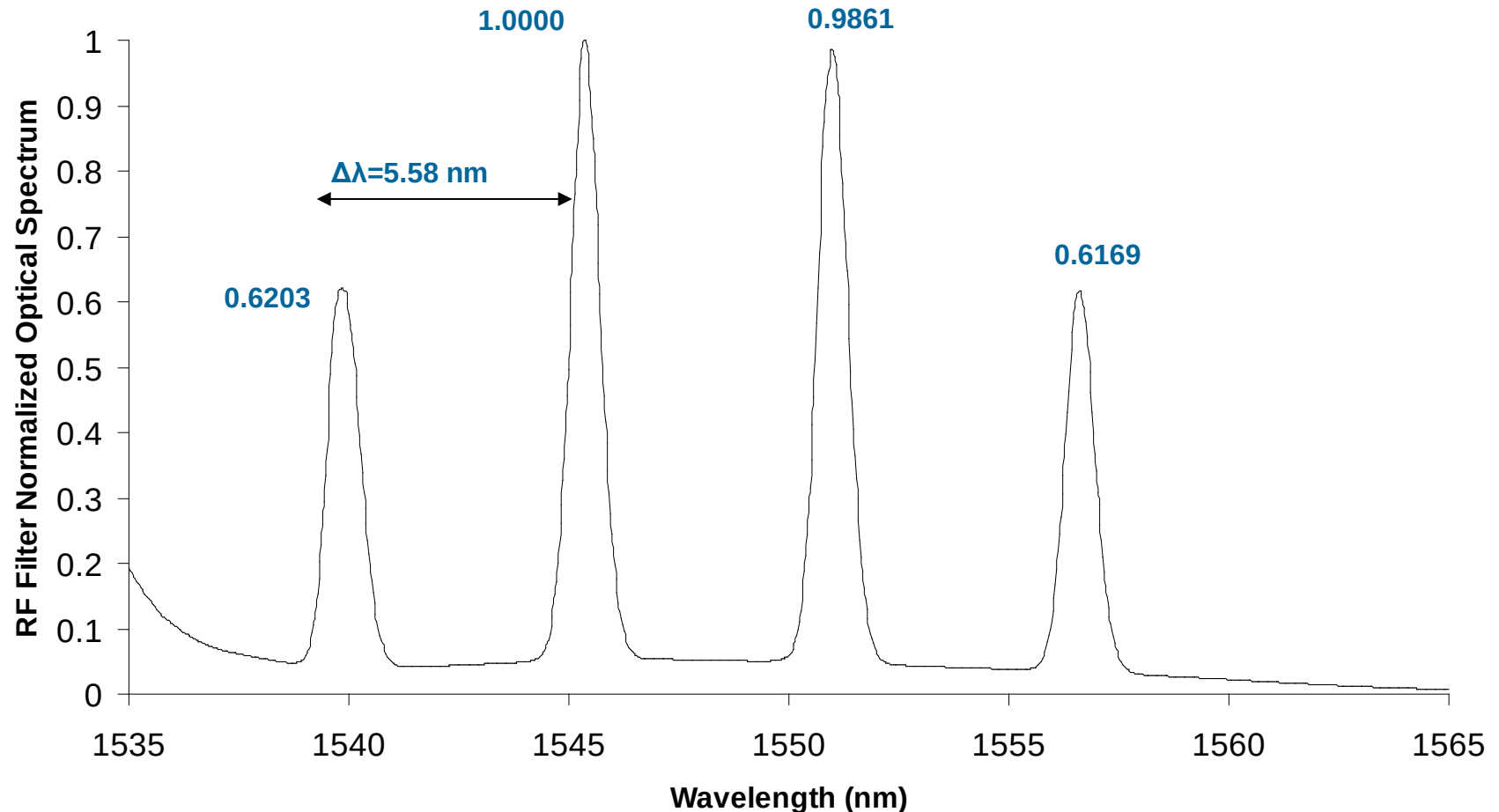
$$f_{null} = 6.75 \text{ GHz}$$

Demonstrated Features of the Two-Tap Notch Filter

- 25 dB RF Notch Depth
- 8.47 dB Optical Loss
- 2 GHz – 8 GHz Bandwidth (0.62 GHz – 18.94 GHz)
- Frequency Resolution – near Continuous
- Compact and Low Component Count Design
- High Speed Operation (34 μ s AOTF dependent filter reset time).

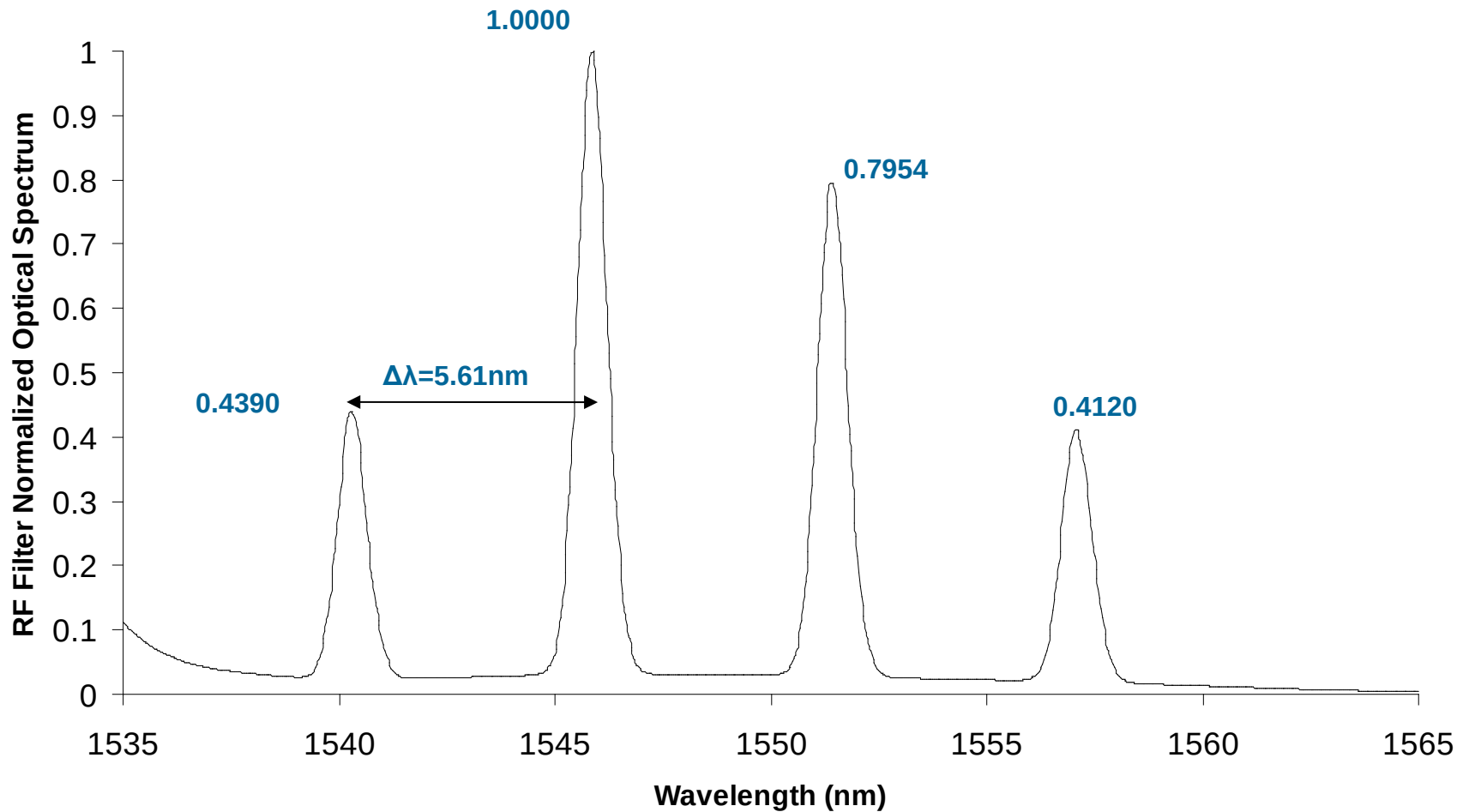
Experimental Demonstration of Four-Tap Filter

Time Domain Impulse Response

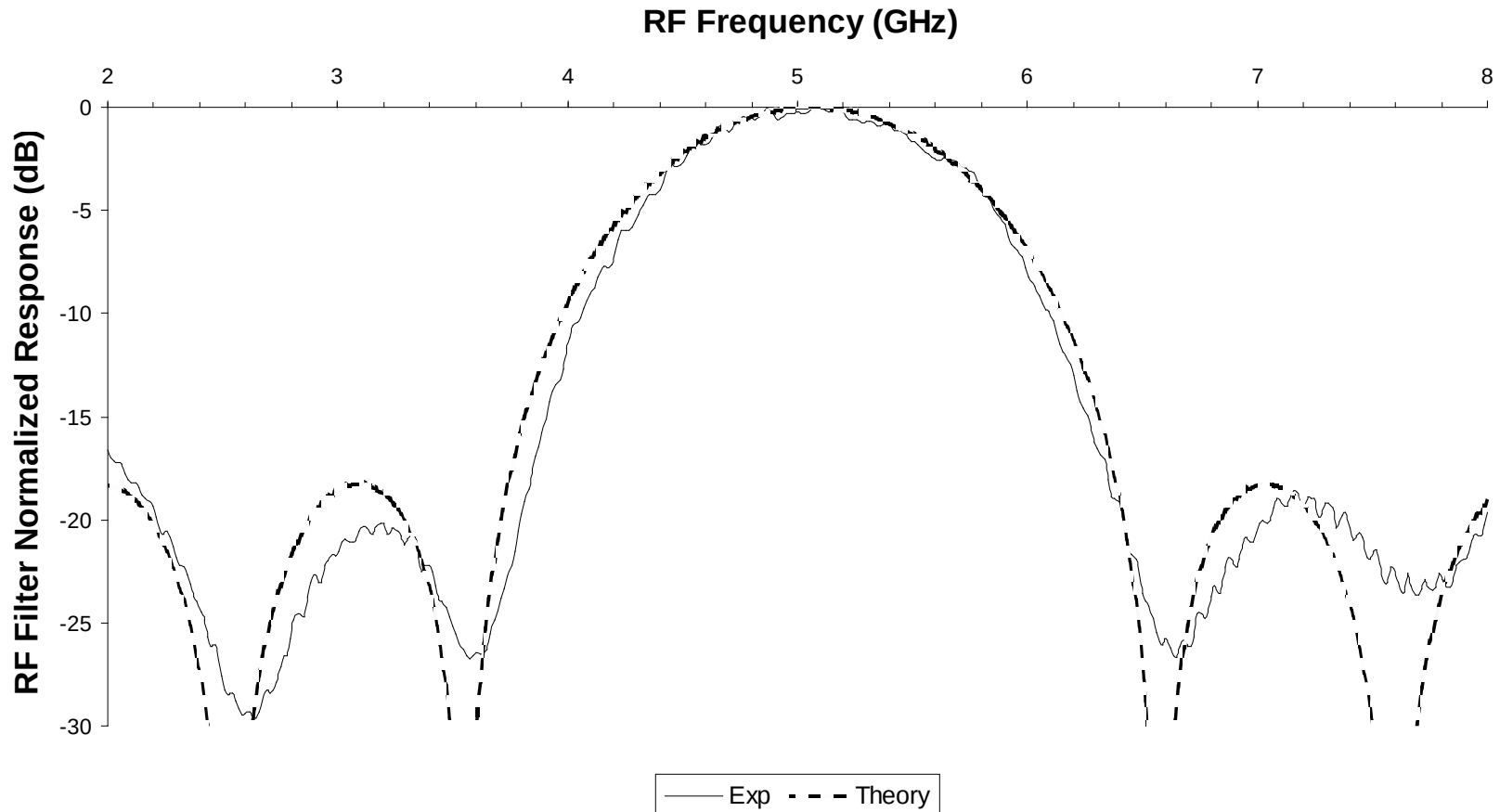


Experimental Demonstration of Four-Tap Notch Filter

Time Domain Impulse Response



Tuning Characteristics of Demonstrated Filter via adjustment of 4-Tap Filter Weights



$$\tau = \Delta\lambda D_{cg}$$

$$\tau = \Delta\lambda * 35.2 \text{ ps / nm}$$

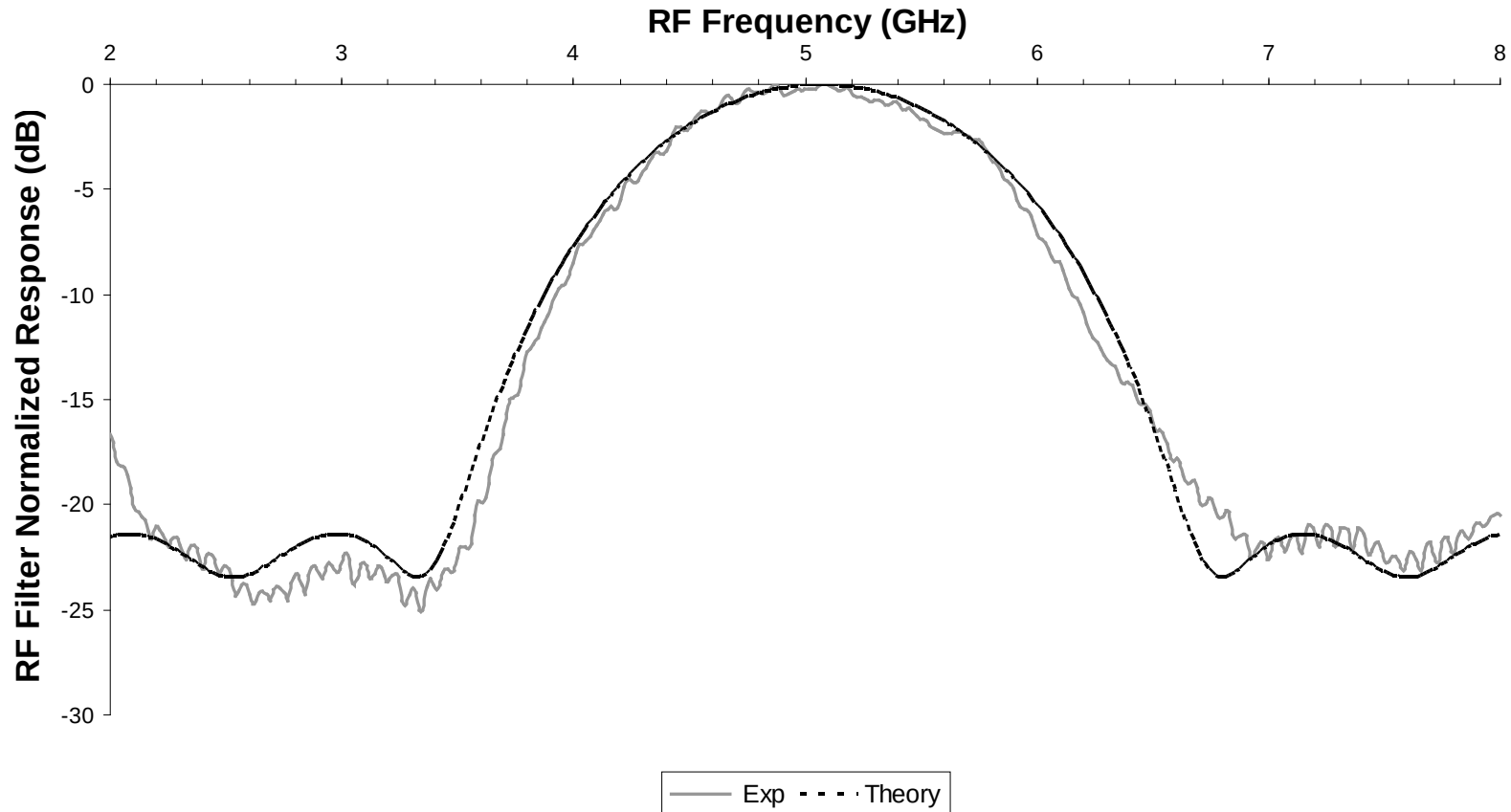
$$f_{\max} = \frac{1}{\tau}$$

$$\Delta\lambda = 5.58 \text{ nm}$$

$$\tau = 196.4 \text{ psec}$$

$$f_{\max} = 5.09 \text{ GHz}$$

Tuning Characteristics of Demonstrated Filter via adjustment of 4-Tap Filter Weights



$$\tau = \Delta\lambda D_{cg}$$

$$\tau = \Delta\lambda * 35.2 \text{ ps / nm}$$

$$f_{\max} = \frac{1}{\tau}$$

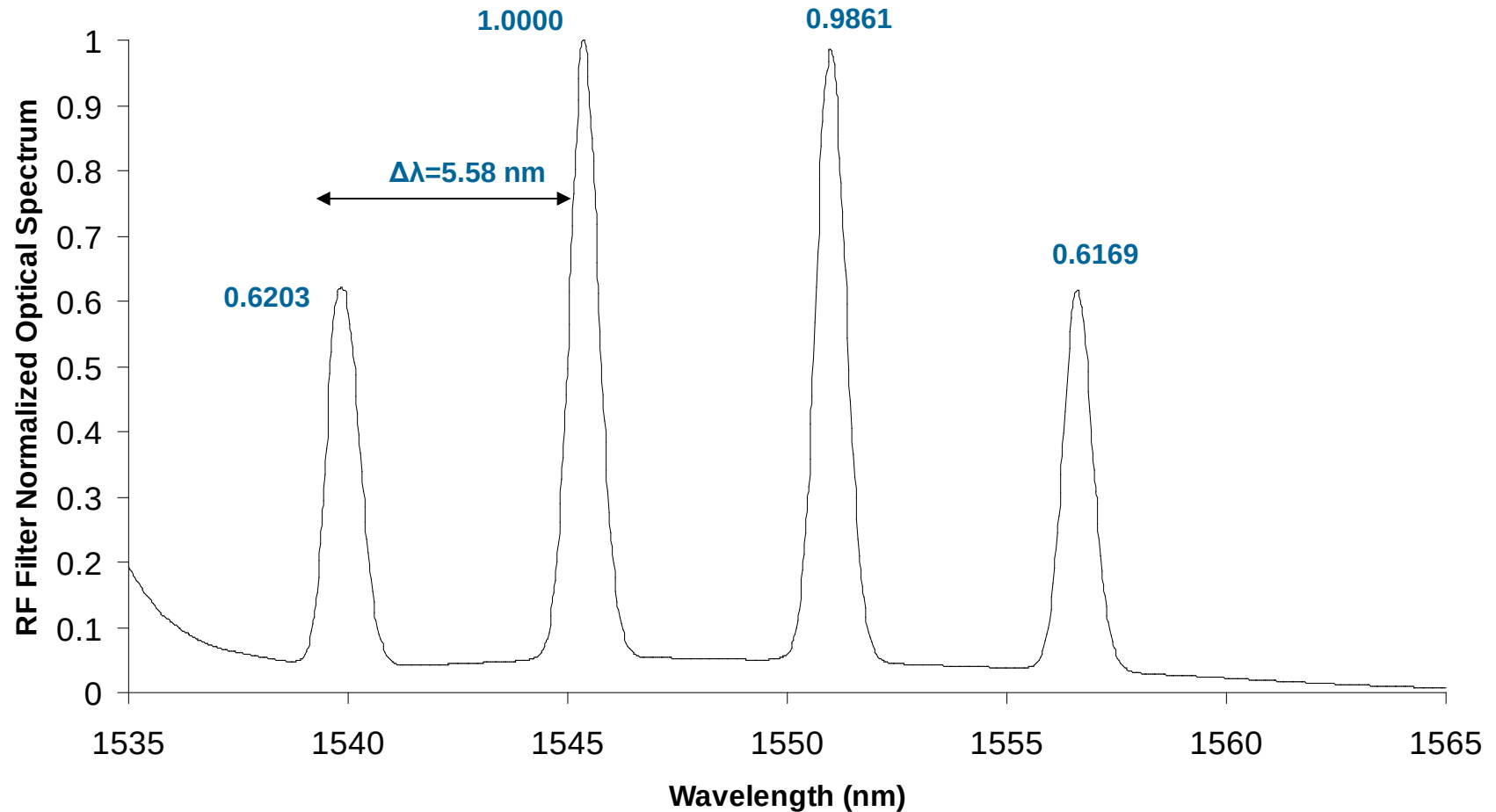
$$\Delta\lambda = 5.61 \text{ nm}$$

$$\tau = 197.5 \text{ psec}$$

$$f_{\max} = 5.06 \text{ GHz}$$

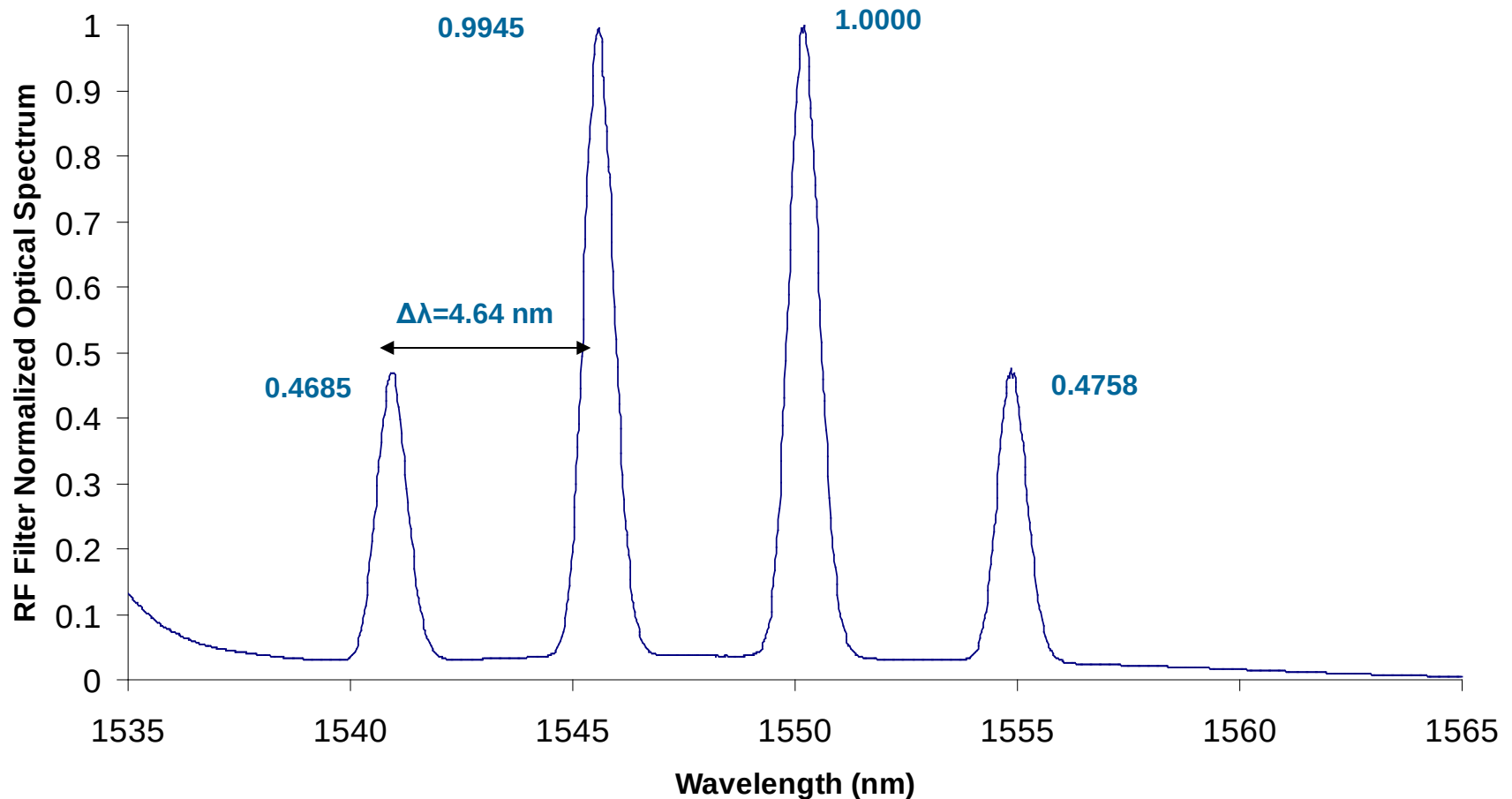
Experimental Demonstration of Four-Tap Filter

Time Domain Impulse Response

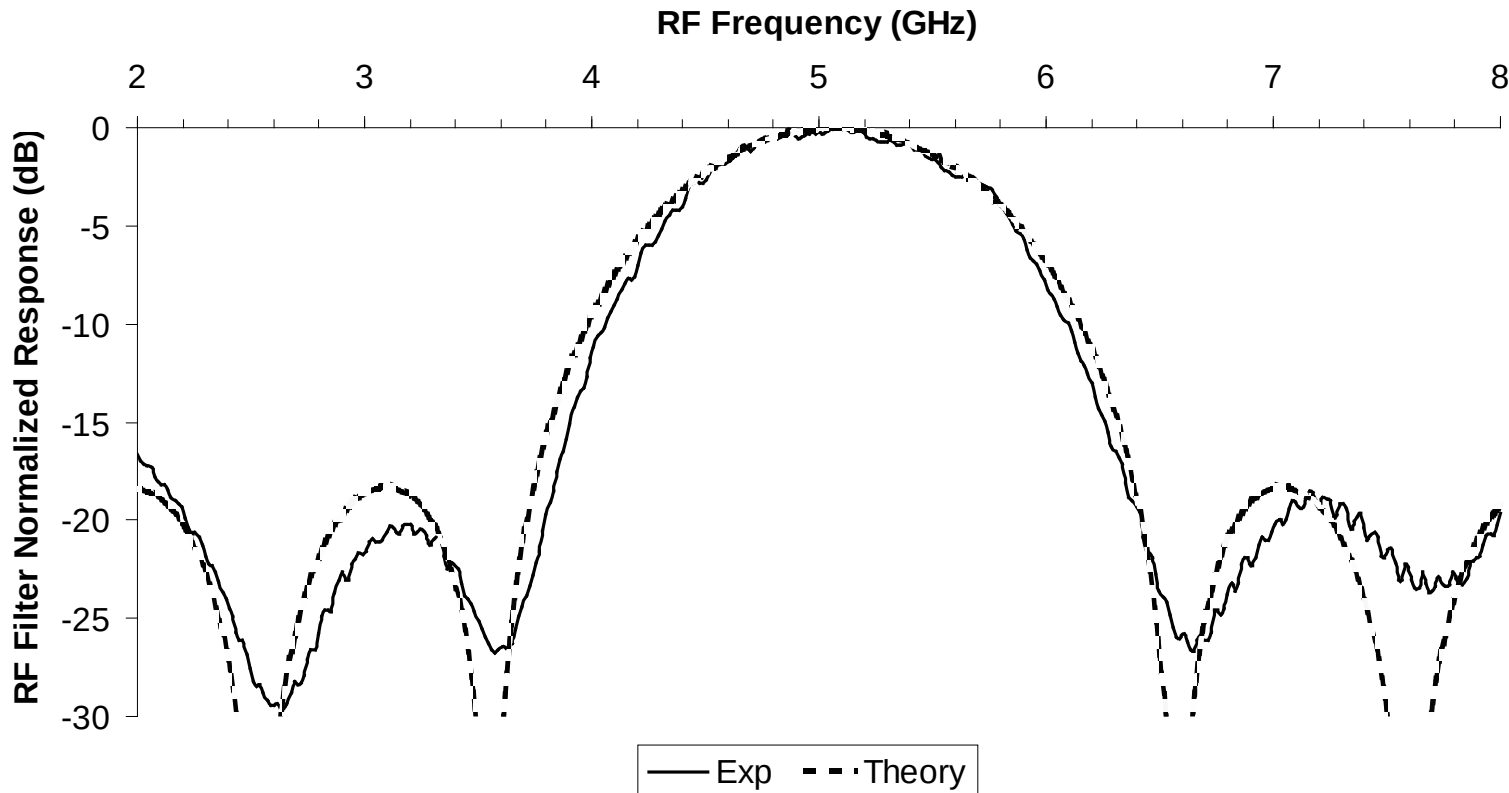


Experimental Demonstration of Four-Tap Filter

Time Domain Impulse Response



4-Tap Filter Frequency Domain Impulse Response - Tuning Characteristics of Demonstrated Filter via adjustment of inter-Tap Time Delay



$$\tau = \Delta\lambda D_{cg}$$

$$\tau = \Delta\lambda * 35.2 \text{ ps / nm}$$

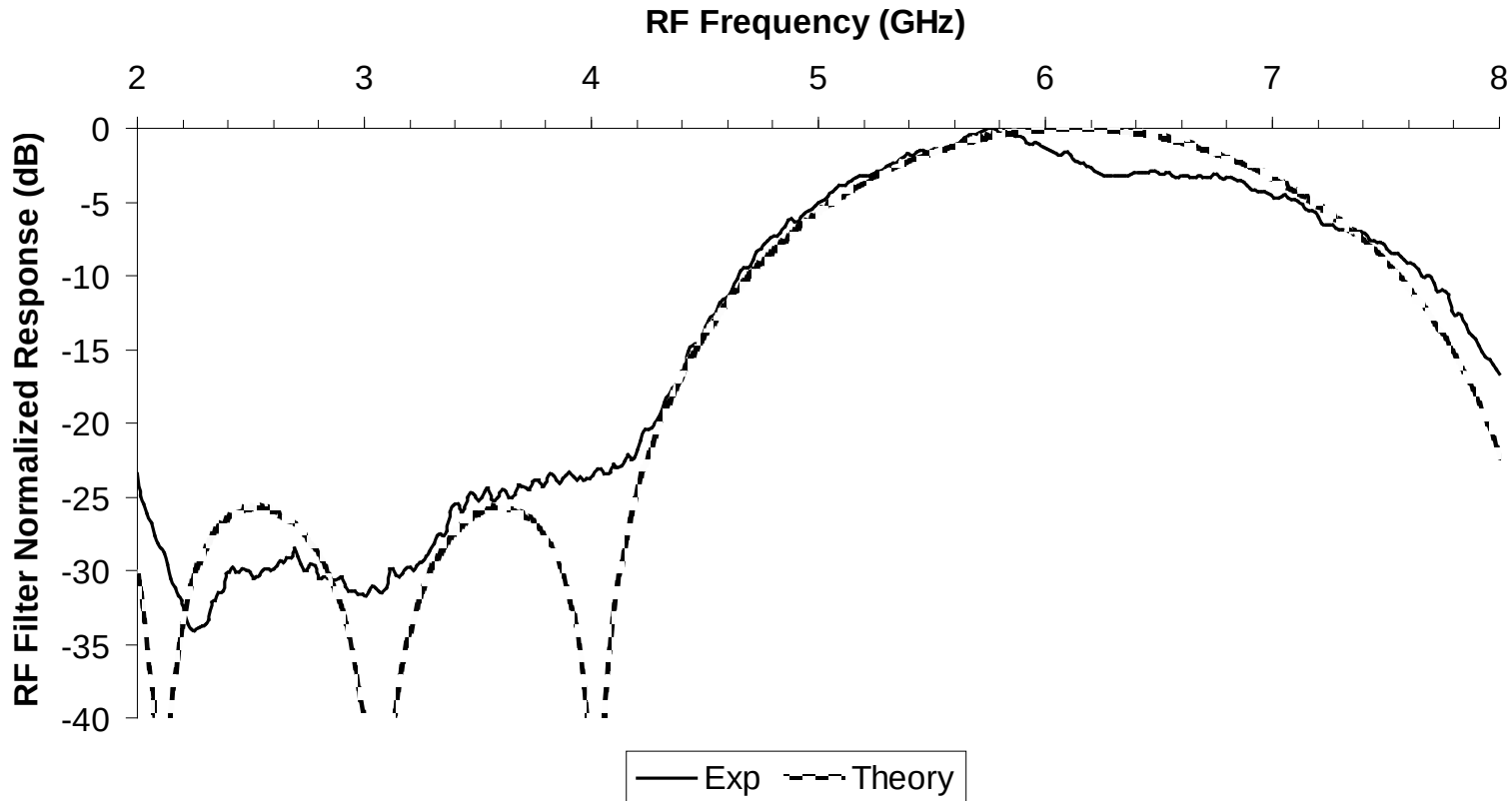
$$f_{\max} = \frac{1}{\tau}$$

$$\Delta\lambda = 5.58 \text{ nm}$$

$$\tau = 196.6 \text{ psec}$$

$$f_{\max} = 5.1 \text{ GHz}$$

4-Tap Filter Frequency Domain Impulse Response - Tuning Characteristics of Demonstrated Filter via adjustment of inter-Tap Time Delay



$$\tau = \Delta\lambda D_{cg}$$

$$\tau = \Delta\lambda * 35.2 \text{ ps / nm}$$

$$f_{\max} = \frac{1}{\tau}$$

$$\Delta\lambda = 4.64 \text{ nm}$$

$$\tau = 163.3 \text{ psec}$$

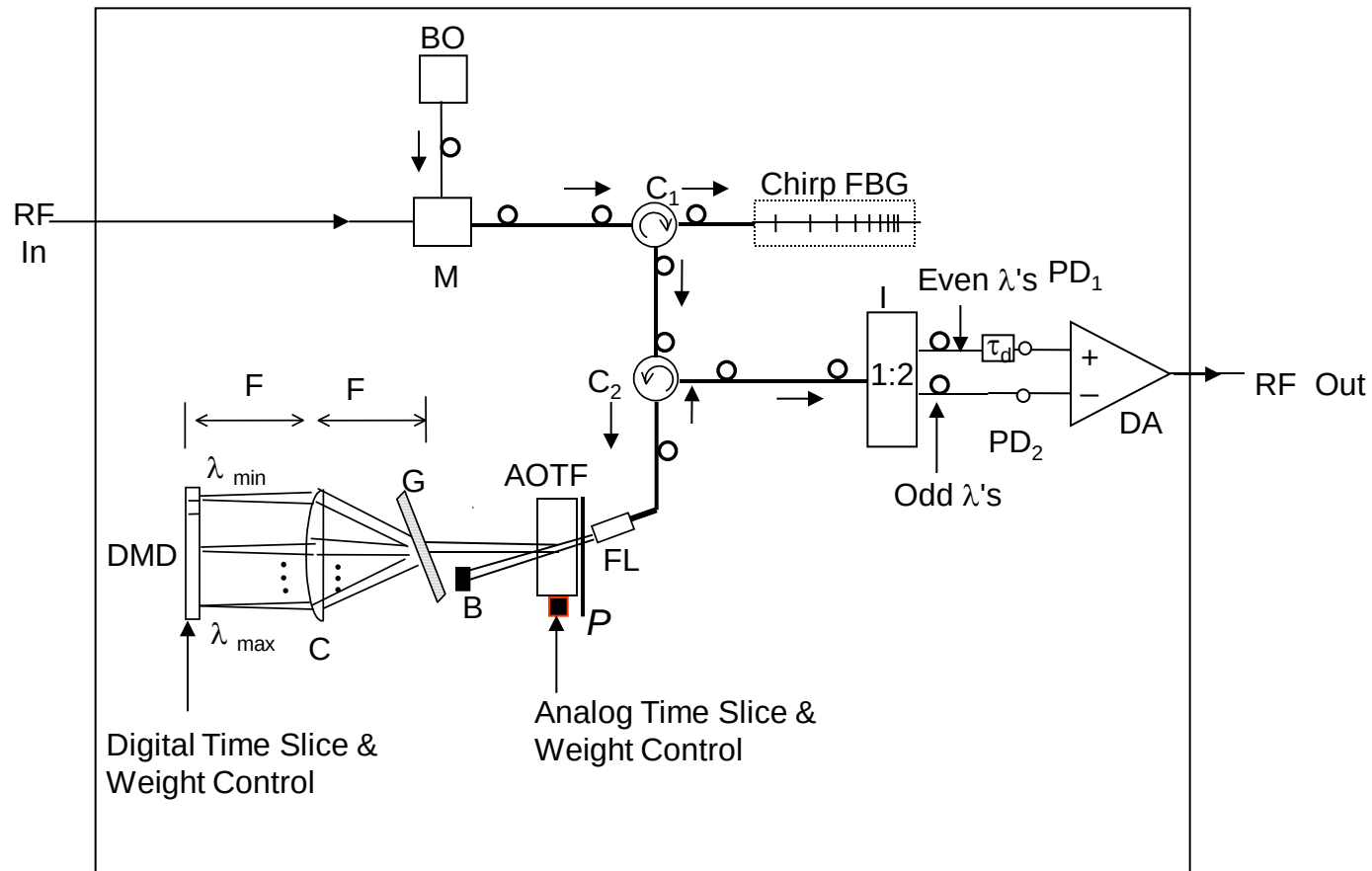
$$f_{\max} = 6.1 \text{ GHz}$$

Filter Capabilities

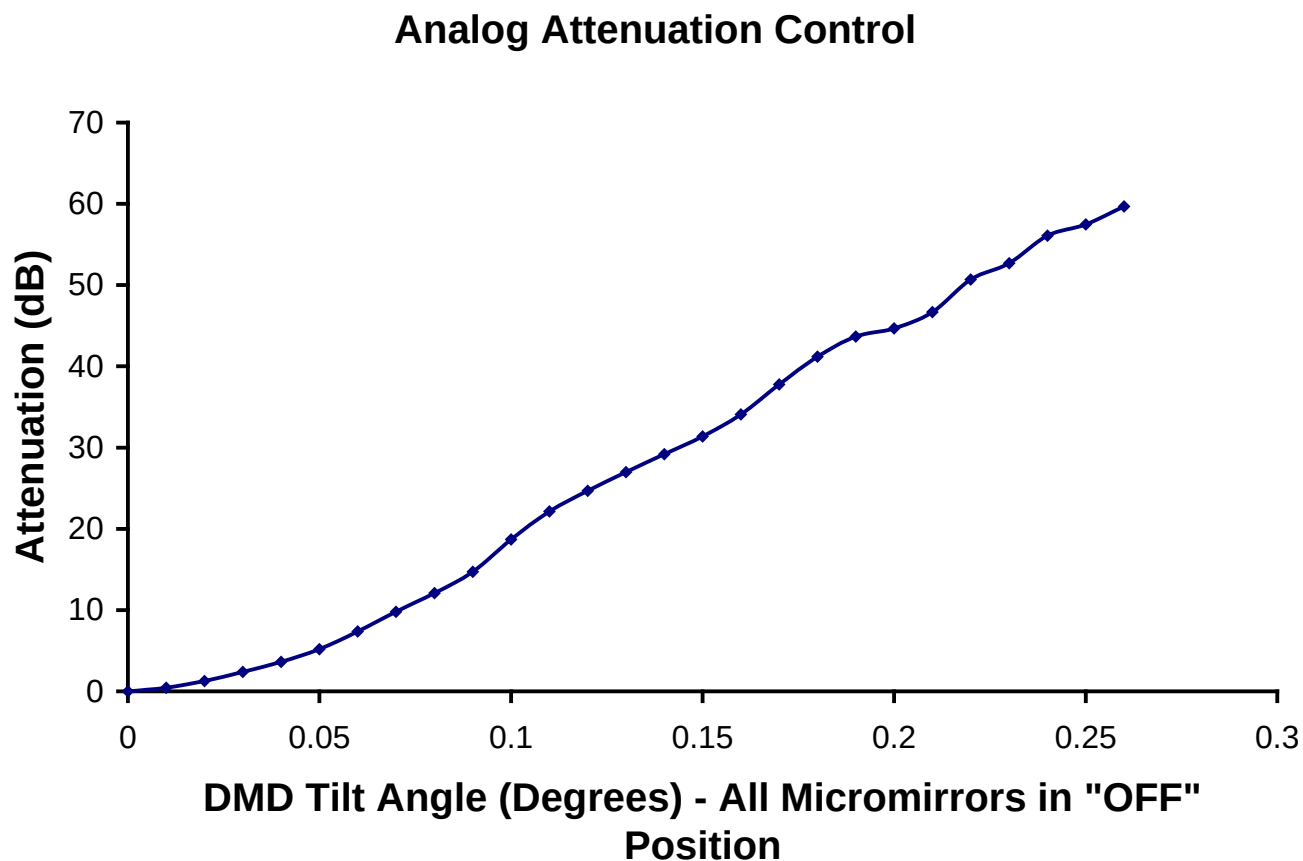
- e.g., 0.5 GHz – 33 GHz Tunable Bandwidth
- Up-to 1000 Time Delay Taps
- Positive and Negative Taps
- RF 70 dB Range Tap Weight Controls
- High Speed Operation (SLM Dependent: ms to microsec to nanosec)
- Compact Module: e.g., 3 in (W) x 5 in (L) x 2 in (H)

Conclusion:
Introduced Most Advanced Optically Implemented RF Filter

RF WIDEBAND HYBRID TRANSVERSAL FILTER USING OPTICS

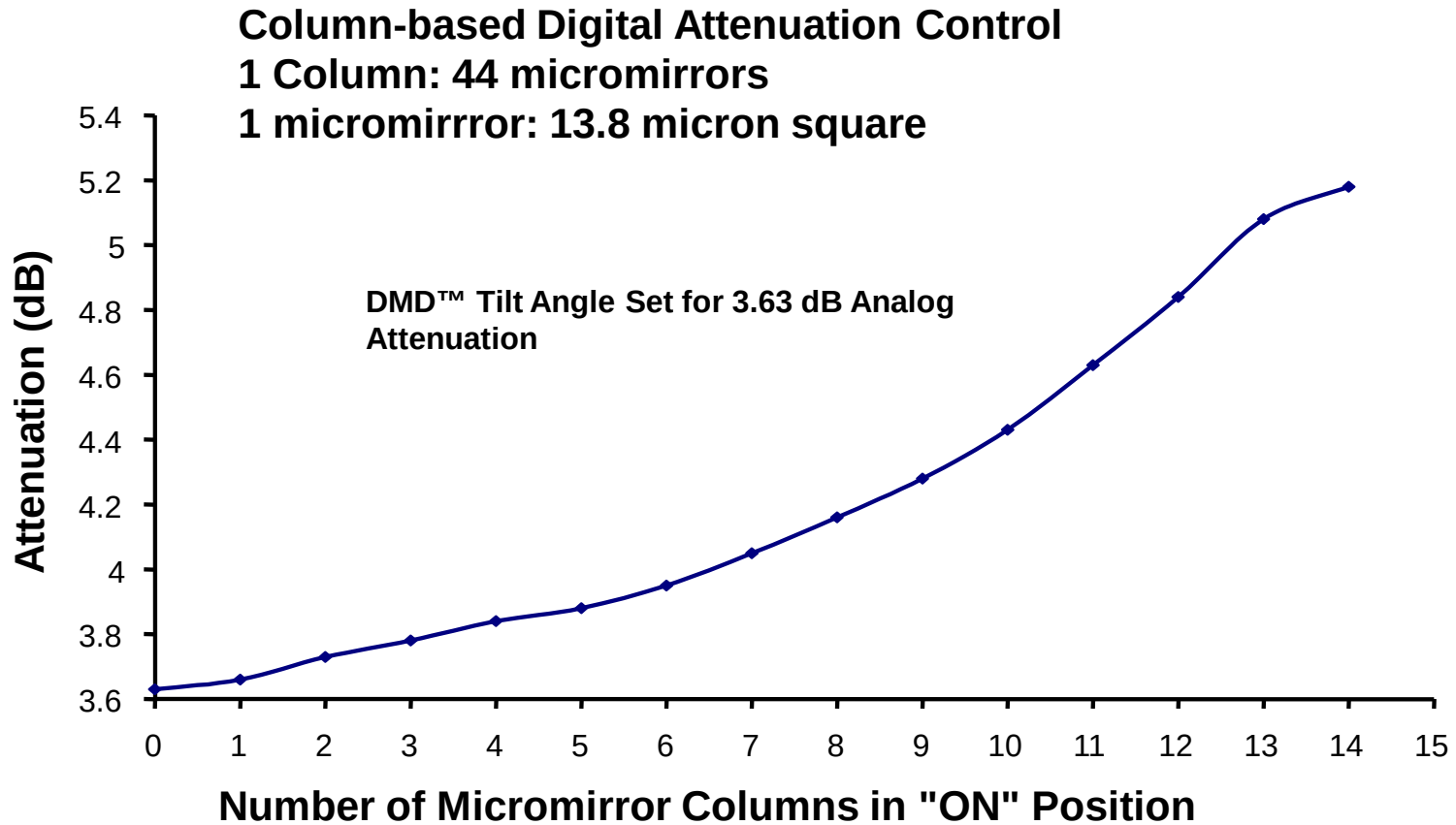


MEASURED CONTINUOUS 60 DB ATTENUATION PRODUCED VIA PURE ANALOG TILT MOTION OF DMD



Attenuation shown is produced by the Hybrid VOA using up-to 0.26° tilt motion.

MEASURED DIGITAL ATTENUATION PRODUCED VIA PURE DIGITAL MICROMIRROR COLUMN CONTROL



The analog setting of the VOA is a 3.63 dB attenuation level.

RETROREFLECTIVE HYBRID MEMS VOA SUMMARY

- Fiber-to-Fiber insertion Loss: 3.1 dB
- Pure Analog Dynamic Range: 60 dB
- Resolution: 0.1 dB
- PDL: 0.05 dB
- Test Wavelength : 1550 nm
- Speed: 1 ms DMD Digital Reset + DMD Tilt Motion

CAN WE MAKE A BETTER HYBRID DESIGN VOA ?